The Journal

OF THE

Royal Aeronautical Society

A Monthly Illustrated Magazine devoted to all subjects connected with the Navigation of the Air.

EDITED FOR THE

COUNCIL OF THE ROYAL AËRONAUTICAL SOCIETY

BY

J. LAURENCE PRITCHARD, Fellow.

VOL. XXX.

1926.

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THE JOURNAL
OF THE
ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Fellow

No. 181 JANUARY, 1926. Vol. XXX.

NOTICES

Donations to the Society

The Council gratefully acknowledge a donation of £50 from the Anglo-American Oil Company, Limited, to the funds of the Society.

Lecture Times

Particular attention of all members is drawn to the alteration of times of lectures from 5.30 to 6.30 p.m.

Conversazione

Sir Samuel Hoare, Secretary of State for Air, has kindly consented to attend the Society's Conversazione on Tuesday, January 12th, which is being held to celebrate the Society's sixtieth birthday. H.I.H. Prince Chichibu will also be present. Members and their friends will have an opportunity of inspecting the wonderful collection of exhibits in the Aeronautical Section of the Science Museum, which are the most numerous and representative of any collection in the world. The String Band of the Royal Air Force will play during the evening and refreshments will be provided.

Change of Subscription Rates

At the Special General Meeting held on December 30th, 1925, it was decided to alter the subscriptions and grades as follows:—

Grade.	*Entrance Fees.* £ s. d.	*Subscriptions.* £ s. d.
Fellow	3 3 0	5 5 0
Associate Fellow	3 3 0	3 10 0
Associate	—	(with Journal) 2 2 0
		(without Journal) 1 1 0
Student	—	1 1 0
Member	1 1 0	2 2 0
Founder Member	—	1 10 0

Special General Meeting

At the Special General Meeting which was held on December 30th, 1925, the alterations of the Rules as proposed by the Council were approved. The chief alterations are those concerned with the formation of a new grade of the Society, to be entitled "Associates." This grade will have the right to put the letters "A.R.Ae.S." after their names, and will include ground engineers and others employed in a technical capacity in the manufacture or operation of aircraft, who have, in the opinion of the Council, sufficient qualifications to warrant their election.

The subscriptions to this grade will be two guineas with the Journal, or one guinea without the Journal.

It will be noted that the grades of Associate Member and Foreign Member have been merged into the grade of Member, giving to these grades the privilege of being able to borrow books from the Library. The subscriptions have been made uniform at £2 2s.

One Member who has had his subscription reduced has asked the Secretary to place the balance to the credit of the Library Fund. It is hoped that other Members will follow his example.

The Council have also been drawing up new rules to form branches of the Society. Full particulars of the new rules for these branches will be published in due course.

A revised edition of the Rules is in the press and a copy will be sent to each member in due course.

Library

The following books have recently been received and placed in the Society's Library:—"The Poetry of Flight," by Miss S. Wolfe Murray; "A Discussion on Ionization in the Atmosphere and its Influence on the Propagation of Wireless Signals," brought out under the auspices of the Physical Society of London and the Royal Meteorological Society; "The Aircraft Year Book," edited by the Aeronautical Chamber of Commerce of the United States of America; Report for the Year, 1924, by the National Physical Laboratory; Report on Civil Aviation, by the Department of Defence, Dominion of Canada; "The Strategy and Tactics of Air Fighting," by Major O. Stewart; "The Air and its Ways," by Sir Napier Shaw; "Aeronautical Meteorology," by W. R. Gregg; "E. T. Busk," by M. Busk; "With Seaplane and Sledge in the Arctic," by G. Binney; "My Polar Flight," by R. Amundsen; and "The German Air Raids on Great Britain, 1914-1918," by Captain J. Morris.

Members are reminded that they can borrow books by post if they pay for the carriage both ways. It is hoped to be able to get out lists of the books available in the Library under various headings, similar to the list of books recommended for Students.

Students' Section—Programme January-May, 1926

Thursday, Jan. 28th, 6.0 p.m.—In the Library. Informal Discussion on "Air Travel." Mr. Handley Page, Fellow, in the chair.

Saturday, Feb. 6th.—Visit to Croydon Aerodrome. Meet at Trust House entrance at 3.0 p.m. sharp. Capt. H. R. Gillman, Associate Fellow, will conduct the party round.

Thursday, Feb. 18th, 6.0 p.m.—In the Library. Lecture and Discussion, "Bernoulli and Aerodynamics," Mr. M. S. Hooper.

Saturday, Feb. 27th.—Visit to the de Havilland Aircraft Company's Works at Stag Lane Aerodrome. Meet at Burnt Oak Tube Station at 10.30 a.m. sharp.

Thursday, March 11th, 6.0 p.m.—In the Library. "Experimental Flying from the Pilot's Point of View," by F.O. R. L. Ragg, R.A.F.

Thursday, March 25th, 6.0 p.m.—In the Library. Lecture and Discussion, "Stalled Flying," by Mr. S. S. Hall.

Thursday, April 8th, 6.0 p.m.—In the Library. Lecture (to be announced later).

Further visits to be arranged for May and June.

Will those students who wish to take part in any visits kindly let the Secretary know as early as possible so that the necessary arrangements can be made?

The Month's Arrangements

January 5th, 5.30 p.m.—In the Library. Council Meeting.

January 7th, 6.30 p.m.—In the Library. "The Experimental Stress Analysis of Frameworks, with Special Refreence to the Problems of Airship Design," by Professor A. J. Sutton Pippard, D.Sc., Fellow.

January 12th, 8.30 p.m.—The Society's Sixtieth Birthday. Conversazione in the Aeronautical Section of the Science Museum.

January 21st, 6.30 p.m.—In the Library. "The Schneider Cup Race, 1925," by Major J. S. Buchanan, Associate Fellow.

January 28th, 6.0 p.m.—In the Library. *Students' Meeting.* Informal Discussion on "Air Travel."

February 4th, 7.0 p.m.—Joint Meeting with the Institution of Automobile Engineers, at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2. "American Aircraft Engine Development," by Mr. C. L. Lawrance.

February 6th.—*Students' Section.* Visit to the London Terminal Aerodrome, Croydon.

J. LAURENCE PRITCHARD, *Hon. Secretary.*

THE ROYAL AERONAUTICAL SOCIETY

(Scottish Branch)

SIXTH ANNUAL REPORT, FOR YEAR ENDING 31ST MAY, 1925.

Preliminary

The Executive Committee have pleasure in submitting their Sixth Annual Report describing the activities of the past year. While in many ways there are circumstances relating to aeronautical science and usefulness which have been inspiring and cheering, on the other hand there have been circumstances calculated to depress the eager mind. All would like to see the potentialities of the great discovery of the Brothers Wright, of twenty-one years ago, more rapidly materialised on behalf of the British Empire than has yet been found possible. Nothing would produce more useful results in our present difficult circumstances if the recent advances in research could be applied practically in little time and without undue cost.

Some Events of the Year

1. The winning of the prize of £2,000 in the autumn of 1924 at Lympne of the "Wee Bee" of Messrs. Beardmore and designed by a member of our Executive, Mr. Shackleton, was a matter of great gratification to the Executive and hearty congratulations were accorded to Lord Inverairn and the designer. For the second time, in August, 1925, a win has to be recorded for the "Wee Bee" machine at Lympne, under the skilful pilotage of our member, Captain Kingwill, and to maker, designer and pilot our congratulations are extended.

2. An excellent event in the way of propaganda was the visit of Mr. Alan Cobham, winner of the Round Britain Air Race in 1924, who came immediately on his return to lecture on his Flight to India with Sir Sefton Brancker, who was engaged in planning out the Air Route to the East. It was a matter of importance not only as regards the public meeting in the evening, but also the lecture to 400 Cadets of the Public Schools of Glasgow. Mr. Cobham has followed this feat by his flight to Africa and back to Croydon in one day and distributing newspapers en route, and also by flying in a D.H. Moth light air machine of 27 h.p. from Croydon to Zurich, a distance of 500 miles each way, with a petrol consumption of 20 miles per gallon. The whole 1,000 miles was flown in one day, Mr. Cobham being in the air $13\frac{3}{4}$ hours, and the cost of the flight not more than £5. This marks another milestone in the scientific history of aeronautics.

3. The Executive have followed with interest the movement for the establishment of an Air Force Reserve, and also the proposed Association of the Air Force movement of the formation of an Officers' Training Corps with the Glasgow Territorials' Association. It is interesting to note that Mr. James G. Weir has been co-opted as a member of the Glasgow Territorial Association in this connection.

4. The proposed formation of a Flying Club for Light Air Machines in Glasgow has been noted with interest, and the Royal Aeronautical Society may be able to encourage this movement.

5. The Executive have followed the flight of Ammundsen, in connection with the attempted discovery of the North Pole, with the most profound interest, and his wonderful fight for life. That this intrepid man should have come home

alive is indeed wonderful. The impress of the machinery and technical side of scientific aeronautics on the geographical branch of scientific study, especially in excessive cold, occasions interesting food for thought.

6. The Executive heartily congratulates their esteemed colleague, Professor Gordon Gray, on his exhibition of the gyroscope investigations and discoveries at Burlington House, before the King and Queen, and also at the Royal Society Soirée in connection with the Greenwich Observatory 250th Anniversary.

Propaganda and Education Committee

The following lectures have been given during the Session 1924-1925:—

Monday, 20th October, in the Royal Technical College, lecture by Air Commodore F. C. Halahan, Director of Technical Development at the Air Ministry, on "Some Interesting Development Problems."

Monday, 1st December, in the Royal Technical College, lecture by Sir Sefton Brancker, Director of Civil Aviation, on "The Relations between Civil and Military Aviation."

Wednesday, 28th January, in the Royal Technical College, lecture by Mr. G. C. Gray on "The Aeroplane in the Next War; Racial Influences and the Work of Aircraft."

Tuesday, 3rd March, in the Royal Technical College, lecture by Mr. A. E. Hagg, of the De Haviland Aircraft Company, Stag Lane Aerodrome, Middlesex, on "Control at Low Speeds."

Friday, 3rd April, in the Large Hall of the Engineers' Institute, Mr. Alan J. Cobham, on "My Flight to India with Sir Sefton Brancker," to the Cadets of the Public Schools of Glasgow, when 400 were present. In the evening Mr. Cobham again lectured in the Large Hall of the Royal Technical College, when there was again an attendance of over 400.

Regarding the work among the students in the University and the Royal Technical College, the results of the Hon. Secretary's work have again been very encouraging. All the engineering classes in the University and Royal Technical College were addressed by him, the students at these numbering 1,000 in all. The number of names of Glasgow engineering students now secured during the last five years who are prepared, if and when the time seems ripe, to take an interest in aeronautical science, now amounts to 1,700, of whom many possess the B.Sc. degree. The number of fresh names secured this year by Mr. Black was 309. In this connection cordial thanks are due to Professors Cormack, Gordon Gray, Mellanby, Muir, Goudie and Dr. Brown for their useful co-operation.

For the work among the youth of Scotland and especially the Boy Scouts and the Boys' Brigade, the Air League of Great Britain has made proposals which may turn out of considerable value to our work. These are at present being considered by the Education and Propaganda Committee and will be reported on at the annual meeting in October.

Finance Committee

This Committee has to report that the subscriptions for the year amounted to £135 11s. 6d. and donations to £15 10s. 0d.; the total income of the Society being £161 18s. 11d. Before the end of this year the Initial Establishment Fund of 1919 will have been exhausted, and before next May it will be necessary for the Finance Committee and for the Executive to consider as to the nature of the financial arrangements which will be necessary in the future. The Society has done excellent work and the useful exertions of the Hon. Secretary have been willingly rendered while the only allowance made has been for the necessary outlays and office expenses. The amount which has been paid to Head Office has

amounted in all to £392 7s. 3d., and the Executive feel that the time has come when the Scottish branch might be permitted by the Head Office in London to work out its own salvation in the matter of finance until better times come.

INVERNAIRN, *Chairman.*

J. BUYERS BLACK, *Hon. Sec.*

ABSTRACTS OF ACCOUNTS FOR YEAR ENDED 31ST MAY, 1925

Receipts.

	£ s. d.	£ s. d.
Balance of Funds as at 31st May, 1924		232 11 4
Entry Money, Subscriptions and Donations—		
Entry Money	2 2 0	
Annual Subscriptions	135 11 0	
Donations	15 10 0	
		153 3 6
Interest on War Loan and Deposit Receipts	... ...	5 17 10
Gain on Realisation of War Loan	... ...	1 0 6
Refund of Income Tax	... ...	1 17 1
		£394 10 3

Expenditure.

	£ s. d.	£ s. d.
Expenses *re* Lectures	50 16 6	
Less Proceeds from Sale of Tickets	20 4 0	
	30 12 6	
Printing	13 3 3	
Advertising	1 14 0	
Typewriting Supplies, Stationery, etc.	6 6 0	
Postages, Telegrams and Telephone Calls	23 8 6	
	81 4 3	
Honorary Secretary's Expenses—		
Travelling Expenses 5 5 0		
Clerical Assistance, as agreed by Committee 80 16 6		
Allowance for use of Office, Typewriters and Office Expenses, as agreed by Committee 100 0 0		
Sundries 1 5 0		
	187 8 6	
		268 12 9
Contribution to Head Office, London		25 0 0
Balance of Funds on Hand—		
In Bank on Deposit Receipt	80 0 0	
In Bank on Current Account	16 18 0	
In Secretary's hands	3 19 6	
		100 17 6
		£394 10 3

PROCEEDINGS

THIRD MEETING, FIRST HALF, 61ST SESSION

A special meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, 18, John Street, Adelphi, on Thursday, October 22nd, 1925, when a translation of Senor de la Cierva's paper on "The Development of the Autogyro" was read by Air Vice Marshal Sir W. Sefton Brancker, Chairman of the Society.

Sir SEFTON BRANCKER, opening the meeting, said: I believe that history will record to-day's meeting as an episode of vast significance in the history of aeronautical development. Senor de la Cierva has been good enough to come and show us his new invention, known as the Autogyro. I have seen it fly, and I have talked at some length with him on its performance; I am left with the impression that Senor de la Cierva may well be responsible for the greatest and most important step in aerodynamical progress since the Wright Brothers first proved to us that we could fly with the aid of the internal combustion engine. The lecturer has had the amazing courage and the extraordinary ingenuity to harness centrifugal force and to employ it for the purpose of lifting and transporting weights through the air.

Mr. Wimperis can claim to be responsible for the presence of Senor de la Cierva in England with his apparatus, and he will introduce him formally and tell you his history. There is one thing about him that Mr. Wimperis may not know. Senor de la Cierva, amongst many other activities, has been a Member of Parliament in Spain twice, so his critics at the end of the paper will be dealing with a man who is not only an aeronautical expert of the first degree, but who is also well versed in acrimonious debate.

Mr. H. E. WIMPERIS said: Our guest this afternoon is a distinguished Spanish engineer, Senor de la Cierva. He is going to tell us of a very wonderful flying machine which he has invented. Some of us have seen it flying at Farnborough and the memory of the experience will long be with us.

Senor de la Cierva's Autogyro represents many years of steady work in the course of which he produced, I understand, no less than thirty different successive designs. The machine now in England was brought to this country on the initiative of the Directorate of Scientific Research of the Air Ministry, in order that the qualities claimed for it might be tested in flight.

This machine is, I understand, the property of the Spanish Government and was lent to the inventor for the purpose of these tests; we are accordingly indebted to the Spanish Government for their courteous co-operation.

From the scientific point of view I have no hesitation in describing this invention as one of the most important aeronautical inventions of recent years. But it remains to be seen how far it can be made use of for service or civil aviation; this will naturally depend upon the load that can be carried with a given weight of machine and other such factors. All these we are in process of investigating.

I have now the honour to introduce to you Senor de la Cierva and to ask him to deliver his lecture.

Senor DE LA CIERVA, speaking in French, said that he wished to express in a few words his confidence in the translator and reader of his paper, his thanks for the reception, and expressed his sense of the great honour the Society had

done him in asking him to give this lecture. He also thanked the officials at the Air Ministry and the people who had so kindly taken an interest in the tests at Farnborough for their help. He was sorry that Captain Courtney was not there for him to thank. As they all knew, he had piloted the machine throughout the tests in England, commencing his first flight without previous experience of the machine and after a few minutes' discussion only of its peculiarities.

The slides were arranged in chronological order, showing the evolution of the machine. There were three films; the first was taken in Spain and was of historical value; the second was a Press film taken at Farnborough; the third was a slow motion film taken by the officials at Farnborough. The two latter showed the same type as the first, but with various improvements embodied. He would now let the Chairman read the paper.

THE DEVELOPMENT OF THE AUTOGYRO.

BY SENOR DE LA CIERVA.

MR. CHAIRMAN, LADIES AND GENTLEMEN,

I began to work in aviation in 1911 and experimented with gliders, brought very much into vogue again recently in connection with sailing flight.

In experimental flights on these gliders my brother and I had some rather dangerous falls due to loss of flying speed, the most prolific cause of accidents to aeroplanes in their present form. The problem of removing this source of danger from aviation has seemed to pursue me throughout my aeronautical work, and has directed my investigations up to the present moment.

In 1912 I constructed my first power-driven aeroplane, a biplane, followed by a monoplane in 1913. In 1918 I had constructed a large biplane with three engines which, after most satisfactory trial flights, was wrecked precisely by losing flying speed. The accident diverted all my energies to the solution of the problem of eliminating this danger; for the possibility of losing flying speed and the uncertainties of landing are, in fact, the only faults with which we can reproach the aeroplane, which otherwise is practically perfect in point of speed and manœuvrability.

The two problems are, in reality, one and the same, and apart from more or less secondary considerations the problem is solved if we can find a flying machine with stability entirely independent of its speed and which, consequently, can fly or descend with a wide range of incidence, practically from .0° to 90°, as compared with the narrow range of incidence, 0° to 15°, permissible in aeroplane flight.

In 1919 I had the idea of using as lifting surface a windmill with vertical axis driven solely by the relative wind, a component of which, parallel to the axis, was to be obtained by beating of the wings as in an ornithopter, and this was held sufficient to maintain rotation in horizontal flight. An engine would drive an ordinary tractor airscrew and would furnish power for the beating movement. If the engine stopped the windmill would act as a parachute, permitting a vertical descent. This design remained on paper, for it very soon became clear that a lifting windmill of this kind would turn without any flapping action provided the axis was slightly inclined backwards from the vertical.

The chief difficulty was now the asymmetry of lift on the wings, for the wings rotating against and with the relative wind would have their average velocities through the air respectively increased or decreased, with a corresponding asymmetry of lift and a displacement of their resultant lift from the vertical, leading to a sideways movement and ending probably in a sideslip.

The first solution that suggested itself was the use of two lifting windmills of opposite symmetry and rotation, mounted on the same axis, and this was embodied in the design of my first "Autogyro," to use the generic name given by reason of the fundamental characteristic common to all my designs, of turning automatically.

Figs. 1-3 show Autogyro No. 1 with two windmills of four blades each, on the same axis turning in opposite directions, the axis being mounted on the fuselage of an old Deperdussin, with a 60 h.p. Rhone engine, driving a four-

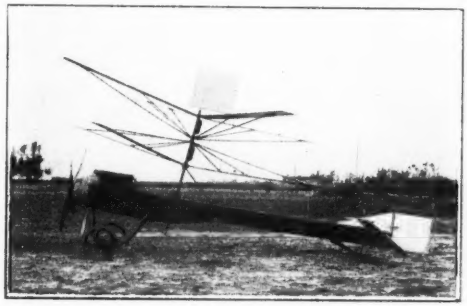


FIG. 1.

bladed tractor airscrew. The controls consisted of an elevator, a rudder and a single aileron mounted vertically on the top of the axis of the two windmills.

Revolution counters fitted to each windmill, separately gave observed values for comparison with calculations. The agreement was satisfactory in the case of the upper windmill, but the lower windmill ran at only two-thirds of the expected speed with consequent lack of compensation of the lateral forces.

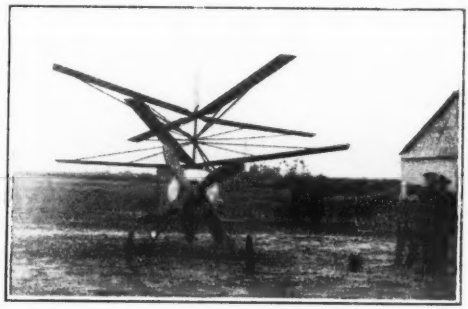


FIG. 2.

A differential gear could have been employed to impose equal angular velocities mechanically, but the increase in the already considerable complication, the mechanical losses and other secondary considerations all led irresistibly to the conclusion that one lifting airscrew only should be employed. An alternative solution for lateral stability was therefore sought along the following lines.

Applying the blade element theory of airscrews it was clear that greater relative speed might be compensated by a smaller relative incidence in elements diametrically opposite.

If it were possible to choose the aerodynamical characteristics of each element and to control its incidence so that the resultant lift couples of the opposed blades (not necessarily of each element but the resultants summed over all elements) should be in equilibrium the problem would be solved.

The detailed computations were laborious, for the compensation must be effective at all incidences. After several formal investigations and innumerable trial solutions I achieved the design of the second type of Autogyro (Fig. 4). It

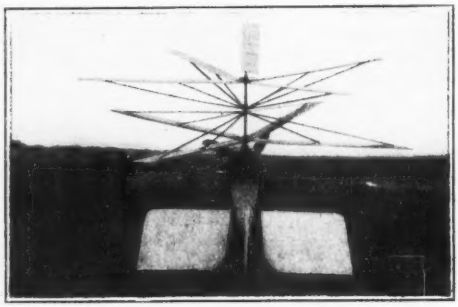


FIG. 3.

consists of a single windmill, with the cantilever blades capable of being set at varying incidence by the pilot, who could thus displace the resultant lift to right or left at will. This is, in fact, a very effective lateral control.

The engine was at first a 50 h.p. Gnome, later an 80 h.p. Le Rhone.

FIG. 4.

The first results were encouraging, for the machine in taxying at the aerodrome of Getafe, near Madrid, in the beginning of 1921, developed the calculated angular velocity of the windmill and an adequate lift. But, unfortunately, as soon as the pilot brought the machine into the appropriate attitude for flight, it inclined towards the wing which was rotating contrary to the direction of flight; in this case the right wing. The rotation of the windmill was clockwise looking from above. (In the latest type it is anti-clockwise.)

It followed that the distribution of pressure did not agree with my assumptions and calculations.

An attempt was made to control the variation of incidence of the blades by means of a lever operated by the pilot, but the same trouble always reappeared, leading to serious damage, the machine being reconstructed nine times in the course of the experimental work.

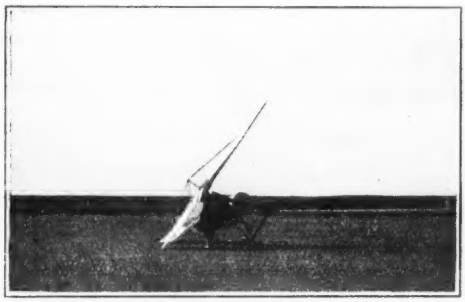


FIG. 5.

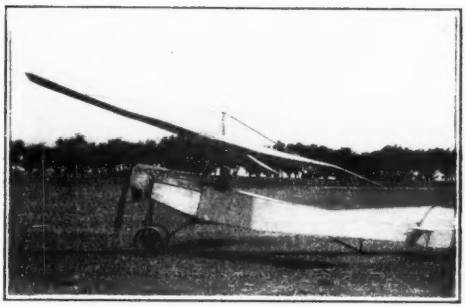


FIG. 6.

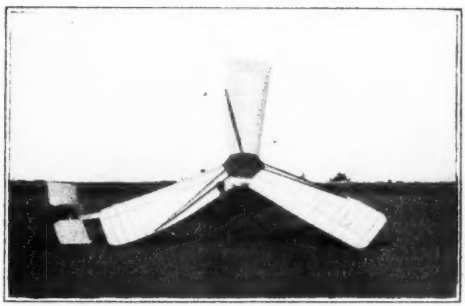


FIG. 7.

After a large number of trial modifications of the wing profile, it appeared that the discrepancies would be accounted for by torsion of the unbraced cantilever blades, which had not sufficient torsional rigidity to withstand twist and consequent change of effective incidence caused by shift of the centre of pressure.

These torsional forces evidently alternate with each complete revolution.

Following on this, the third type of Autogyro was designed, based on the same general principles, but with heavy bracing of the blades to the axis, by streamline high tensile steel wires, as in aeroplane practice.

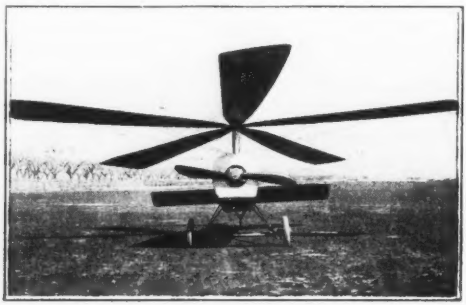


FIG. 8.

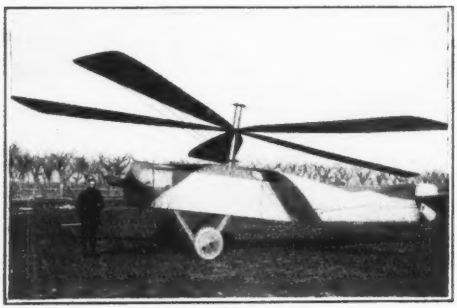


FIG. 9.

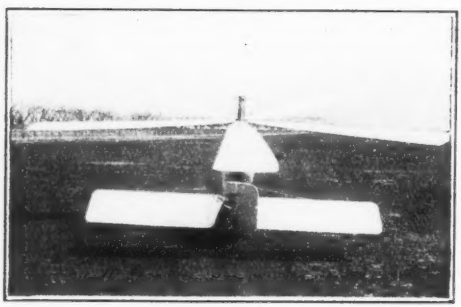


FIG. 10.

Autogyro type 3 was ready for test in the beginning of 1922. It had a lifting windmill of five rigid blades, lateral control being obtained by the differential effect of a large elevator divided into two independent parts right and left. The fuselage was designed to take the resulting torsional couple.

The engine was a 100 h.p. Le Rhone.

This machine showed a closer approach to lateral balance than the former, but always had a tendency to fall over sideways, which the split elevator was insufficient to control. It was damaged and rebuilt four times in the course of these experiments.

The idea of using articulated blades had come to me in the beginning of 1922.

It is a fundamental point in the design of the Autogyro exhibited at Farnborough, affording as it does a complete solution of the problem of stability, and incidentally, of numerous other problems of design.

FIG. 11.

Thus, during completion of the tests of type 3, the first Autogyro of type 4 was already being constructed to my new designs.

This machine had a single windmill with four rotating blades, but instead of being rigidly attached, they were hinged near the root (in the latest designs the hinge pins are at 2° with the axis of the windmill). The blades were thus able to move freely about their hinges, beating the air, so to speak, freely, without

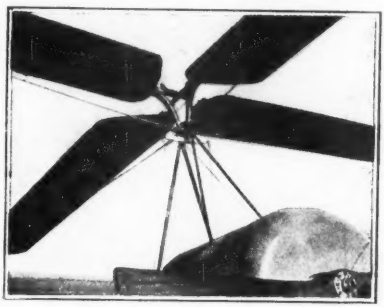


FIG. 12.

any sensible change in their geometrical incidence, the chord remaining always practically parallel to its original position for small amplitudes of beating movement.

Rubber shock absorbers, or "Sandows," keep the wings in position when at rest and prevent them from flapping downwards till supported by contact with the earth or with other parts of the machine.

In rotation, centrifugal forces act on the blades and are large enough to keep them nearly perpendicular to the axis. By the construction the resultant force acts at a point in the axis above the hinge pins.

The aerodynamical and mechanical problem is highly complex, but there is one great simplification which can be stated at once. Since the blades are articulated the total reaction on each blade, that is the resultant of all the air forces and inertia forces, acting on it must pass through the hinge pin.

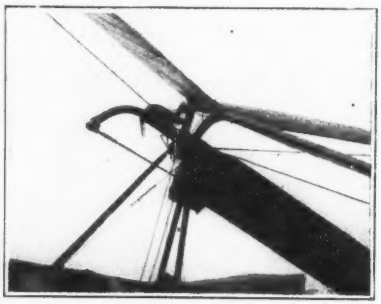


FIG. 12A.

Perpendiculars drawn between hinge pins and axis meet in a common point on the axis. Since these perpendicular distances are small the resultant of the four-blade reactions may be taken as active at this "common point." This resultant is in general inclined slightly to the axis, and by giving an equal and opposite inclination to the axis, the result becomes vertical.

If the centre of gravity is below the "common point" the aeroplane is in equilibrium, in spite of the asymmetry of the forces on the blades.

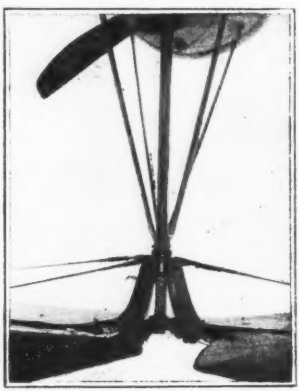


FIG. 13.

The "common point" may be called the metacentre of the air forces and inertia forces on the blade system. It is nearly independent of incidence, speed, etc.

The centre of gravity is relatively very low, hence there are always high restoring forces bringing the machine back to its position of equilibrium. At the

same time there are high damping forces preventing resonance, *i.e.*, oscillations of increasing amplitude about the position of equilibrium, as might be feared from the low centre of gravity.

The damping does not, however, interfere with ordinary manœuvres.

Gyroscopic forces, which would be of the severest nature in a rigid system, cannot be transmitted through the flexible attachment of blades to axis.

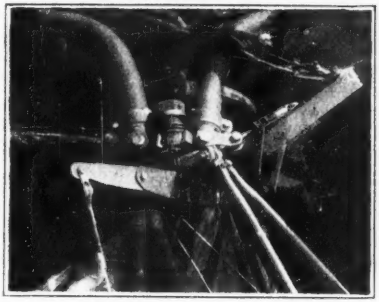


FIG. 14.

Finally the articulated blades form a flexible system in sudden gusts. The inertia forces are ten times the lift forces, the resultant being $\sqrt{(10^2+1^2)}=10$ very nearly. In a gust producing ten times the air forces the resultant would be $\sqrt{(10^2+10^2)}=14.1$ approx., an increase of only 41 per cent. over normal stresses.

In the first machine of this type, lateral control, though unnecessary in theory and it would seem in practice, was provided for by tilting the axis of the windmill to the right or left; but it became immediately evident in the very first tests that the pilot's strength was insufficient to work the control.

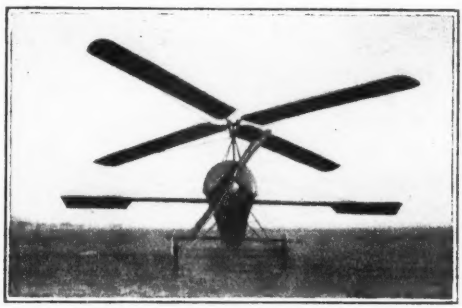


FIG. 15.

After many months of exploration, "crashes," and rebuilding (this particular machine was reconstructed or modified fifteen times in all) I had recourse to a more logical system of control, fixing the windmill axis rigidly and building into the machine two small non-lifting ailerons at the end of streamlined spars.

From that time onward the machine, which had demonstrated in the course of the year 1922 the value of the articulated system, making hops without inclining to the side, was ready to be used in real flight, and on 17th January, 1923, it flew right across the aerodrome at Getafe at a height of several metres.

It was transported thence to the aerodrome of Quatro Vientros (Four Winds), near Madrid, and on 31st January, 1923, carried out a flight of four minutes at a height of more than 25 m., in closed circuit, officially observed and controlled.

It is, so far as I know, the first real flight ever carried out by a machine, heavier-than-air, differing from the conventional aeroplane.

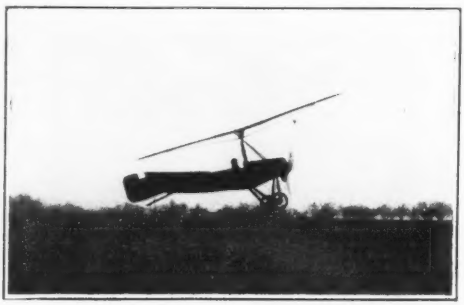


FIG. 16.

FIG. 17.

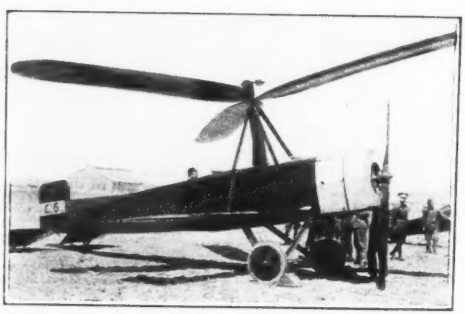


FIG. 18.

The pilot was Lieut. Gomez Spencer, of the Flying Corps of the Spanish Army.

After this success type No. 5 was designed and constructed on the same principles, but with important improvements in detail.

This machine had only three blades and the details of construction were carefully worked out. The engine was a 100 h.p. Le Rhone.

Several preliminary flights were successfully carried out, but before it had been brought to its proper trim it was completely broken up by an accident while taxying.

FIG. 19.

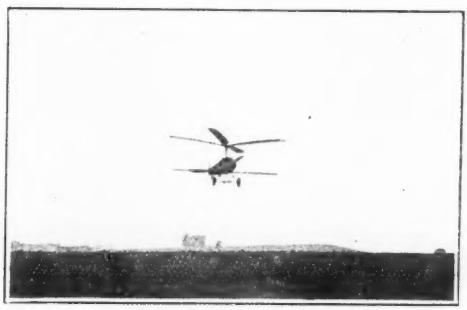


FIG. 20.

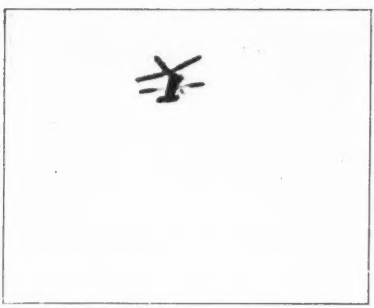


FIG. 21.

At this point the Spanish Army aeronautical authorities took the responsibility of continuing the experiments and sanctioned the construction of any Autogyro of type 6 in the military workshops at Quatro Vientos.

The third machine of this type to be constructed was that shown at Farnborough recently.

It is made up of a standard "Avro" fuselage with a 100 h.p. Le Rhone engine, with two lateral ailerons (non-lifting), a carriage somewhat larger than the standard "Avro," and a four-bladed windmill. The blades have a section in

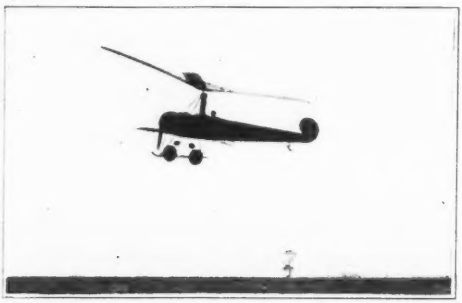
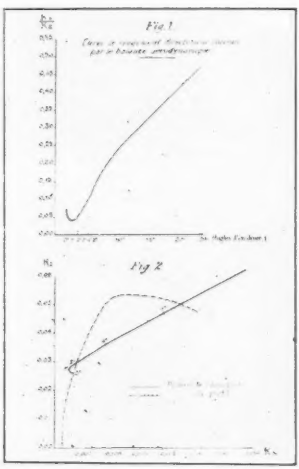


FIG. 22.

the axial plane, designed so that the resultant force at each point is along the blade. Thus, the single longeron, in steel tube, is in pure tension, very nearly, the bending moments being almost nil.

The symmetrical section (Göttingen No. 429) is almost free from movements of the centre of pressure and from consequent torsional forces.



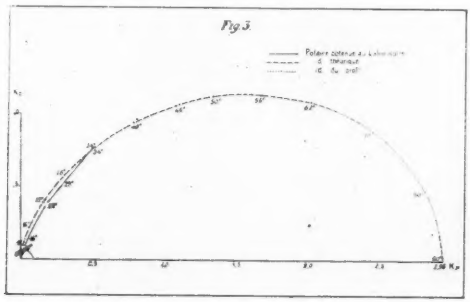
They are mutually braced by wires kept in tension by the centrifugal force on small leaden weights.

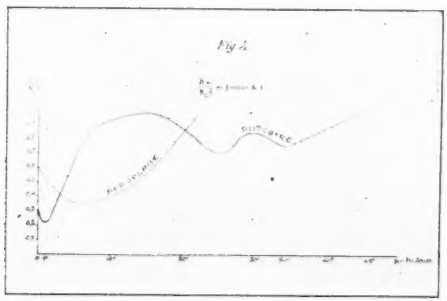
This machine commenced its flights in May, 1924, but other engagements prevented definite trials till December, 1924. On the 9th December, 1924, Captain Loriga, of the Spanish Military Aviation, made his first flight, rising to 200 m. and landing almost vertically.

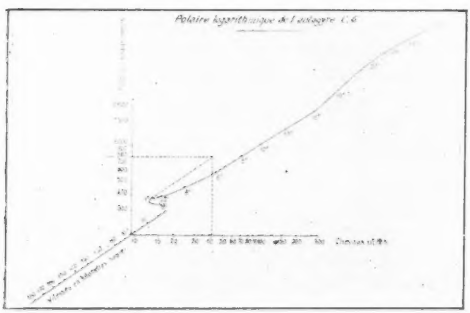
He is unfortunately prevented by serious illness from demonstrating his control of the machine in this country.

On 12th December, 1924, Captain Loriga made a flight of 12 km. between the aerodromes of Quatro Vientes and Getafe, the first air voyage in an Autogyro.

Figs. 21 and 22 show the departure and arrival.







Type 6 has been completely remodelled twice, which gives a total number of 32 distinct machines built and tested in order to arrive at the results demonstrated earlier in this week before many of those present to-night.

Discussion

Mr. Lock said: I think we are all agreed that we have seen to-night one of the most wonderful inventions since the original invention of the aeroplane itself.

Before thanking the Lecturer very much for his most interesting lecture, I should like to ask him one or two questions dealing with the actual working of the machine. First of all, whether he can tell us if there are any conditions which may occur in flight which might stop the windmill from rotating? It seems likely that such conditions might occur when flying at very high speeds. This does not seem likely to occur on landing, but in flying at very high speeds the rotating wings might have a difficulty in maintaining rotation. I should like to know the smallest angle to the wind at which the windmill would maintain rotation.

Secondly, whether there might possibly be a danger of the rotating wings stopping if the machine dived very rapidly at a high speed and then checked itself by raising the elevators as in an ordinary aeroplane when diving and flattening out.

Thirdly, what would be the actual velocity of descent in a very steep glide?

Fourthly, would it be possible for the machine to descend absolutely vertically at a safe speed apart from considerations of stability? It appears that the machine does come down at an extremely steep angle, but we do not know what was the velocity of the natural wind.

I have been very much impressed by the lecture and films and was fortunate enough to see the machine fly at Farnborough. It was one of the most wonderful sights I have ever seen.

The following additional questions were communicated to the Lecturer in writing:—In connection with the first question, whether the wind tunnel tests showed a tendency for the screw to cease to rotate at very small angles of disc incidence, since it was probably possible to obtain smaller angles of incidence in the wind tunnel than could be obtained by the machine in actual flight. In connection with the fourth question, I should like to ask whether you anticipate that the resistance of the Autogyro, in falling vertically, would be very much greater than that of a parachute of area equal to the disc area of the Autogyro, since a simple calculation indicates that a parachute having the same area and loading as the Autogyro would fall at a velocity of between 30 and 40 feet per second.

The CHAIRMAN gave the provisional reply, that if a starter were applied to bring the windmill speed up to 120 r.p.m. the unsticking speed would be about 15 m.p.h.

A device for the speeding up at standstill was the next step in development.

The surface was less than half that of a standard Avro, the weight 600 lbs. more. The speed attained by Captain Courtney was 68 m.p.h. without ailerons, and with reduced weight higher speed would be attained.

Major F. M. GREEN said that he owed a double debt of gratitude to the Author of the paper, firstly for giving us an account of his invention, and secondly for calling it an "Autogyro" and not a "Helicopter." It was not very long ago since the speaker had himself read a paper before this Society in which the possibilities of the helicopter were discussed, and then he gave it as his considered opinion that the chances of this type of aircraft being successful for transport purposes were remote. If Senor de la Cierva had chosen to call his invention a helicopter it would have been unfortunate for the speaker, and he therefore agreed whole-heartedly with the Author of the paper that this successful machine is not a helicopter but an Autogyro.

As it seems very likely that the name of Senor de la Cierva's invention will become a household word, the speaker hoped that we should find a shorter word than Autogyro; perhaps the inventor will help us to find one.

The particular point about which the speaker would like information concerns the rate of revolution of the windmill. It seemed to him that if this did not vary much in speed the structural design would not be difficult. The stresses on the revolving blades depended almost entirely upon the rate of turning, and if under no circumstances would this increase by more than a small percentage above the normal rate of revolutions, then the variation of stress during flight would be much smaller than in an aeroplane of the ordinary type. When the pilot made any sudden manœuvre it was inevitable that the accelerations which resulted should increase the apparent weight of the apparatus. On an ordinary aeroplane of the single-seater fighter class we know that accelerations of five times gravity are not unusual. So long as the rate of turning of the windmill did not increase, the extra loads will take care of themselves, as the inclination of the blades would change so that the resulting force along the axis of the windmill was increased to supply the force required.

In conclusion, Major Green wished to congratulate Senor de la Cierva most sincerely on having brought before their notice what was undoubtedly an invention of the first importance, and he wished also to express his thanks to Colonel Wimperis for having arranged matters so that the demonstration and lecture became possible.

Mr. HANDLEY PAGE said: I should like to join the previous speakers in thanking the Author very much for his interesting paper, and congratulate him on the successful results which he has achieved after many years of research work.

On Monday last I had the pleasure of seeing the machine from the air, being a passenger in one of our three-engined aeroplanes which was flying over Farnborough. From the air the machine looked for all the world as though it were a toy spinning top which a boy had wound up and sent into the air.

From a technical point of view, it would add greatly to the value of the paper if the Author could give some technical data in regard to the lift and resistance of his machine. After all, the Autogyro is an aeroplane and follows the same laws governing an ordinary aeroplane. The inventor has only changed a fixed plane for a rotating one, and by so doing has obtained a much wider range of lift and, presumably, also of drag. It would therefore be of great interest to all the technical members of the Society if he could add to his paper some details of lifts and resistances over a wide range of angles of inclination of the machine and speeds of rotation of his planes.

One has heard a good deal in the last few days in the popular Press about machines of this type being able to land on roofs, but I would remind Senor de la Cierva that for such a landing one must presumably have a flat roof. Most of the roofs in England are not flat, being designed to drain off the rain. If, however, the machine did find a flat roof on which to land, how would it fly off? There seems at the present time no means by which the machine could make a vertical ascent such as is associated with the helicopter. I should be very glad if Senor de la Cierva could give further technical information as to the shortest distance in which the machine could ascend and whether there is any possibility of incorporating the full helicopter effect for an ascent. I should be very interested to know what the loading is on the planes of the Autogyro. It would seem that the speed on landing is greatly reduced, but has this reduction in speed been obtained at the expense of top speed? From the figures given it would appear that the machine is slower than an ordinary Avro. If the top speed were increased to that of a normal machine, would Senor de la Cierva propose to do this by cutting down the area of the propeller blades and so increasing the loading, and when the loading was so increased, would not the slow speed be correspondingly increased? There are many ways in an ordinary aeroplane by which a greatly decreased slow speed can be obtained, but it is nearly always at the expense of top speed.

Senor de la Cierva mentioned that the tip speed of his blades was constant, no matter what the size was, and presumably under all conditions of the varying attitudes of the machine in flight this would hold good. Is this due to some basic fundamental theory, and if so, could Senor de la Cierva give reasons for it?

There is another side upon which one would like further information, and that is from the constructional point of view. The blades of the propeller are supported on a single tubular axis. Are they not, as in an ordinary blade of an aeroplane propeller, subject to torsional forces, or are these small in comparison with the centrifugal forces? Would not difficulties arise if the aircraft were made in a large size?

I would like to know whether Senor de la Cierva could give any comparative figures as to what the weight of his machine is compared with that of an ordinary aeroplane.

Finally, Senor de la Cierva is to be congratulated on having both the perseverance and financial resources at his disposal to carry his experiments through to the successful result which we have seen demonstrated in this country under Captain Courtney's piloting.

Professor BAIRSTOW said: I have listened with very great interest to the account which has been given of the Lecturer's early attempts to produce the Autogyro. Although the pictures have been extremely interesting it appears to me that they have not given quite so good an account of the machine as they might. It made a great impression on me to see it come down some hundreds of feet at an angle of 60° to the ground and then run forward only a few yards. That, of course, is the feature of the Autogyro on which most stress has been laid, and that seems to be its chief merit. Although the complete aircraft can go forward at 20 m.p.h. in still air the tips of the screw themselves are moving at 150 to 200 m.p.h.—depending a little on the conditions of flight. Consequently one can see in that fact a reason for very high lift coefficients and the very high wing loading of 25 lbs./sq. ft. without departing from a knowledge of the existing aerofoils to-day or the necessity for assuming new and unexplored types of air flow. That encourages me to go a little further; although Major Green says he is pleased that the apparatus has not been called a helicopter, and in fact has some important differences from the latter, yet one of his remarks in a lecture to the Society some years ago bears very much on the efficiency of the Autogyro at high speeds. If an aerofoil is to be used at all with the normal types of airflow, it must have a limiting value to the ratio lift/drag which is not at the choice of the inventor and which is available for the aeroplane. The work done in moving the aerofoil under best conditions is proportional to the distance they move and the aeroplane in going straight from point to point does least work. The coiled path of the aerofoils of the Autogyro screw is much larger, and as a necessary consequence the device must be less efficient at high speeds than the aeroplane. It should, perhaps, be pointed out here that high speed aeroplanes do not fly at their best angle of incidence and that the restriction may not apply to the Autogyro. On the other hand, the Autogyro has still to achieve speeds in excess of 70 m.p.h.

In the construction of this machine one can but admire the extreme mechanical simplicity of all its parts. The hinging of the blade screws at the central hub, the bending of the blades so that there is tension only along the spar are admirable devices for avoiding stresses not only in the screw but in the aircraft generally.

It seems to be one of the rare occasions when nature has presented gifts to the inventor. A screw is produced which auto-rotates and is free from high stresses. It proves to be very stable and the flapping essential in the stress problem does not adversely affect the aerodynamic behaviour. There are, however, some gifts withheld as usual; the possibility of hovering in still air or of rising vertically from the ground does not come with the device as exhibited.

I would like to congratulate the inventor on his device and on the extraordinary success which his tests have had in this country.

Mr. MANNING said: Mr. Handley Page has already mentioned that we should like to know more about what is generally known as the lift-drag ratio of the wing itself. I understand from what General Brancker has said that the rotationary speed of the wings is constant under all conditions. I presume that consequently the wing lift would vary as the square of the speed of the machine, and that as the weight of the present machine is understood to be 2,000 lbs., an 8,000 lb. machine with a speed range of from 20 to 130 m.p.h. could be made with the same diameter of revolving wing. It would be interesting to have some information as to the resistance of the wings of such a machine. In any case, the machine has one important feature—its low speed is 10 m.p.h. and its top speed 68, so that it has a speed range of 6½ to 1, and that has never before been attained.

I congratulate the inventor on his most important contribution to the science of aeronautics.

Mr. HARRIS BOOTH said: Two months ago I should have had a lot of questions to ask, but since then I have had the great pleasure of seeing his machine fly in Spain and carry out all the tests that were asked of it, and now I have seen his films I cannot think of anything to ask him. I can only congratulate him again.

Captain SAYERS: There are many questions I should like to ask the Author. Many have already been asked, others require further consideration than has been possible this evening. In common with other speakers, I would congratulate Senor de la Cierva upon having produced an extraordinarily interesting and entirely novel aircraft—an achievement second only to that of the Wright Brothers.

One gentleman at Farnborough, having seen the machine make four flights, said, "I have seen it, but I don't believe it." There is some excuse for his incredulity. It is very difficult to estimate the possible future of this type. By giving the wings a speed of rotation which is independent of the forward speed of the machine as a whole it is possible to reduce the landing speed indefinitely—in fact to zero. As forward speed can obviously be produced, a speed range of zero to something—an infinite range in fact—is possible. The present machine claims 10 m.p.h. to 68 m.p.h.—a very big range indeed on a high horse-power loading. Obviously there is room for very much experimental work in order to see how far this speed range can be extended up the speed scale.

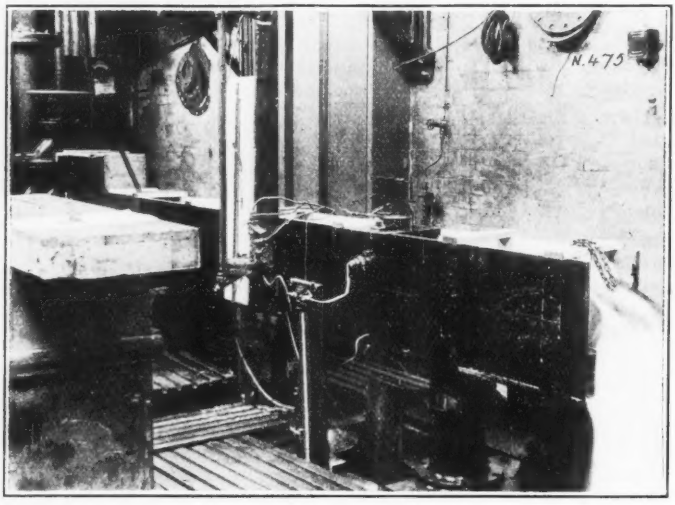
In any event, this Society is to be congratulated upon having secured from the Author one of the most important and epoch-making contributions in its recent history.

Mr. J. L. HODGSON said that he also wished to be among those who congratulated Senor de la Cierva on his epoch-marking achievement. As in the case of the Wright Brothers, the main advance he had made was that he had achieved stability of his lifting surfaces under flying conditions. The solution he had come to was an amazing and an unexpected one. But, brilliant though it was, it seemed inevitable that any device which depended upon flexible propeller blades and lead weights slung on wires would in the end prove but a temporary expedient. The flexible wing of the Wright aeroplane had very quickly become a thing of the past.

Some years before Senor de la Cierva commenced work upon the first of his 32 machines, namely, in 1915, the speaker had, in an attempt to solve the helicopter problem, carried out elaborate tests on propellers working at positive and negative speeds of advance[1] and also inclined at various angles to the direction of motion.

These tests were the first quantitative tests ever made at negative speeds of advance, or upon propellers inclined to the direction of motion. The tests at positive and negative speeds of advance were published in a paper entitled, "Tests on Model Propellers," which was read before the Institution of Automobile Engineers in 1917, and which it would probably be worth while now to reprint in the Society's proceedings.[2]

The curious instability which occurred at moderately low negative speeds of advance, which showed that three different propeller speeds and three different torques would give the same thrust at the same speed of fall should be noted (see Figs. 4 and 5 of the 1917 paper).



The photograph shows the apparatus, illustrated in Figs. 2 and 2a of the 1917 paper, being used to test a propeller working at a small inclination to the direction of motion in a rectangular flume passing about 100,000 gallons of water per hour. These tests on inclined propellers, which were very elaborate, have never been fully published. Certain data from them were however used in criticising Major Green's attack on the helicopter in 1923. In the course of that discussion the writer, while agreeing that the work on helicopters as then being pursued by the Air Ministry was futile, said:—

> "If one imagined a helicopter which had horizontal motion before it got off the ground (see Fig. 20 of the paper before the I.A.E.), such a machine could get off the ground by running along and gradually climbing, and would require very little more horse-power than the equivalent aeroplane. Similarly, if the engine broke down and it was still possible to maintain the stability of the machine, it could glide down as the aeroplane does."

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[1] The negative speeds of advance corresponding to various rates of fall or movement; either without, i.e., "free engine," or with only inadequate engine power.

[2] The paper also summarises tests taken on propellers of eleven blade sections and twelve blade outlines, and having 2, 3, 4, 6 and 8 blades. It also gives a systematic method of solving problems which involve variables which are connected by empirical relations.

This was only repeating what had previously been said in the 1917 paper, viz. :—

> "The same series of tests upon inclined propellers also showed that it would be possible to construct helicopters of very much smaller size than the unwieldy, hovering machine first considered; provided that these smaller helicopters ran along the ground so as to obtain initial velocity before rising,"[3]

and showed that so far back as 1915 the speaker, as a result of many months of research, had clearly seen that the helicopter problem would be most easily and surely tackled by means of machines which had horizontal motion and not (with our present ratio of horse-power to weight) by machines which attempted to hover.

A machine which roughly embodies these ideas was sketched in various attitudes of flight in Fig. 20 of the 1917 paper. The only essential feature in which that machine differed from the one now developed by Senor de la Cierva was that two symmetrically placed propellers rotating in opposite directions were used for balancing the torques and lifts in place of the single propeller used by Senor de la Cierva. This single propeller was the most notable part of Senor de la Cierva's great achievement. The system sketched by the speaker in 1917 had however the advantage that rigid propellers could be used, provided that these were so made or supported that they would not be damaged by bumpy landings. Their use would probably become inevitable in the case of big machines, and there was no need to limit the number of propellers to two (see Fig. 18 of the 1917 paper).[4]

The speaker's 1915 tests were also of interest because they were the first accurate quantitative tests taken on propellers in a closed tunnel—as against the whirling arm of Langley (see Fig. 2 of the 1917 paper); and also because the tests were taken in water (dimensional equations being used to allow for the "scale" effects), which enabled low speeds and high thrusts to be obtained with small and easily made propellers.

The speaker had been developing the technique of such water tests made in connection with air problems since 1909.

In conclusion, the speaker very much regretted the lack of imagination on the part of the Air Ministry of this country as compared with that of Spain. Had the necessary support been forthcoming in 1915, or later, it is almost inevitable that the great step now made by Senor de la Cierva would have been made by English engineers.

Major Low said: I must congratulate Senor de la Cierva on a very remarkable scientific success, and it begins to look more and more probable that he also will score a practical success in the near future. But that does still lie in the future. I think practically the whole range of the performance can be analysed by the usual blade element theory which in combination with the Prandtl corrections will suffice to tell us all about this machine. But there is a new combination of known physical properties and this leads to new complications in the routine calculations which will take a considerable time for our airscrew experts to work out. But I believe this can be done along well-known aerodynamical lines.

Senor de la Cierva has established a reputation for making good all his claims, he has claimed no more than he has performed, and that is a very valuable reputation to establish.

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[3] I.N.A., p. 288 (1917).

[4] Appendix I. of this paper, which deals with the helicopter problem, will be found reprinted in the Proc. of the Aer. Soc., Vol. XXVII. (1925), p. 337-341.

In conclusion he would refer to one of the important questions raised. Professor Bairstow had pointed out that as the blades must travel farther than the aeroplane the energy expended by the drag must be greater. But it must be remembered that the blades are long and narrow and have no bracing, so that their drag is a small proportion of the drag of a complete aeroplane. The body travels at the normal speed and the increased work is in respect only of a small fraction of the total, so that the effect is not so unfavourable as at first sight it might appear.

He thanked the Author for his paper and for the introduction of a new and intensely interesting problem of aircraft design to the aeronautical world.

Mr. WIMPERIS said: I think the Society is very much to be congratulated upon having got Senor de la Cierva to give us this lecture and our Transactions will gain greatly by its incorporation. No doubt the Lecturer will find it possible to include an appendix of technical matters such as the relationship of the rotational speed to the area of the wings and the load carried. Of course in an invention of this kind, an invention in which the wings are so hinged at the hub as to be capable of being folded up like an umbrella blown inside out, it is natural to speculate as to safety. Perhaps the most effective way to envisage the safety of the device is to ask what a pilot would have to do if he wanted to kill himself, supposing he was flying in an Autogyro. In an ordinary aeroplane there are several obvious ways by which he could attain his end, but in an Autogyro it might prove more difficult. I should like to know whether should he bank very suddenly, or loop the loop, would he then be likely to succeed in his object?

When I first saw this machine in the air I realised what courage must have gone to the first flying of machines of this character. I certainly felt with our Chairman that Captain Courtney, who flew it in this country, showed uncommon courage. We had to have someone to take the place of the Spanish pilot who fell ill, and Captain Courtney did it with complete success. When I saw this machine in flight with no wings, and looking rather like a rotating St. George's cross, and felt that I did not know what was holding it up, it reminded me of the saying of that other famous Spaniard, Sancho Panza, that "behind the cross stands the devil."

Sir SEFTON BRANCKER said: With regard to the discussion, the Author has asked me to say that he would be most grateful if all those gentlemen who made queries during the discussion, and any others who wish for further information, would communicate with him by letter. He will in due course answer them in full.

I agree that the films do not really do the machine justice. They show it taxying at great length, which gives the impression that it is making a long weary struggle to get off the ground; this is not at all so in actual fact.

This invention has caused a certain amount of despondency and alarm amongst some of our designers and constructors. It certainly is rather disturbing to have this completely new idea thrust upon us. We have most of us been sceptical about the helicopter, and here suddenly we have a machine which does practically everything that the helicopter sets out to do with the exception of vertical climb.

Mr. Wimperis raised the question of the impossibility of committing suicide on such a machine. I went into that question very carefully with the Author, and he assures me that a pilot, even of my ability, which you all know is not of the greatest, could not hurt himself, no matter what he did in the air.

It has one serious drawback to my mind. It seems that it is going to do away with the skilled pilot; we shall have nothing to do but to navigate in the future!

In addition to the other questions which are going to be sent to Senor de la Cierva, I propose to furnish him with the specification and performance of one of our standard air transport machines and ask him what that machine could do if its planes were replaced by an Autogyro. His reply should be extremely interesting.

There is one point which has not been emphasised during the discussion, but upon which the newspapers have laid considerable stress. Too much importance is attached to the fact that this machine in case of a forced landing can land very slowly and in a small space. I think that in air transport we have reached a point of reliability where no one would dream of completely changing the design of the fleet in order to attain this end. We must stop having forced landings and not design new machines for this sole purpose. What is of much greater importance is that this new type of aircraft should be able to rise from a very small space. It has not done it yet because no mechanism exists for spinning the windmill up to flying speed before taking off, but when this is done it should climb rapidly after attaining a forward speed of only ten miles an hour. This will revolutionise the problem of providing air ports near great cities.

We must remember that this is only the first experimental step. There are many problems and difficulties which will present themselves. For instance, the cooling of the engine. I think that you will all agree with me that we owe to the Author our most sincere gratitude for placing his invention before us and writing this paper. We would like to congratulate him again on his really magnificent achievement, an achievement which many of us believe will have a revolutionary effect on aviation in the future.

Colonel J. D. Fullerton, Royal Engineers (retired) (*contributed*): (1) The great point about this machine is, that it enables a landing to be made nearly vertically, so that only a small space is required for the manœuvre.

(2) The machine itself somewhat resembles the ordinary aeroplane, but it has one very important point of difference, viz., the supporting planes are replaced by an approximately vertical airscrew, which when put in motion by the horizontal advance of the machine, revolves and lifts the whole apparatus in the air. The airscrew itself is of an unusual pattern, as by a system of hinged joints, the drifts of the advancing and retiring blades are equalised, and any tendency of the machine to rotate round the propeller axis is prevented.

(3) The general action of the machine appears to be as follows: When the tractor screw is put in motion, the machine advances in the usual way, but at the same time the air pressure developed rotates the lifting screw and raises the machine in the air; the faster the horizontal speed the greater being the lift produced.

(4) When it is desired to descend, the tractor screw is shut off (at any suitable height) thus reducing the horizontal velocity to a very small amount, and the whole machine descends, very much upon the principle of a helicopter descent, the rate of fall depending upon the design of the machine.

No information is at present available about the weights, surfaces, etc., of the apparatus, but it is clear that since the horizontal velocity can be made very small, and the vertical velocity can be reduced to suit any particular conditions, landing should be very nearly vertical.

(5) The machine is most ingenious, but some further information is required. For instance, how does the speed compare with that of an ordinary aeroplane of the same weight and power; also how is a steep dive carried out without straining the vertical propeller axis?

REPLY TO DISCUSSION.

Senor Cierva has supplied the information necessary for the following replies:—

In answer to the general queries as to area, rotational speed and loading of windmill blades, by nearly every speaker—

Blade area $= 5.5 \times .75 \times 4 = 16.5$ m.^{2}
Total mass 900 kg.
Blades $40 \times 4 = 160$ kg.
Loading $= 900/16.5 = 54.5$ kg./m.^{2}
Available power 90 h.p.

The maximum flying speed at 90 h.p. was about 30 m./s. or 108 km./hr. The slowest flying speed was about 15 m./s.

The landing speed with descent at 30° was about 4 m./s. horizontal, 2 m./s. vertical; the disc being nearly horizontal and therefore about 30° to flight path.

In vertical descent the speed was about 3-4 m./s., the disc being nearly perpendicular to the vertical flight path.

The angular velocity remains about constant at about 130 r.p.m.

This is due to the condition that there is no torque transmitted by the shaft which runs freely on its bearings.

The total weight is also constant and the root mean square speed is nearly constant, hence the r.p.m. remain nearly constant.

With regard to Mr. Lock's question as to stopping at small disc incidence, this implies very high power and very high forward speed. There should be no serious difficulty with any probable horse-power and speed range.

With regard to climb, rate of climb depends on excess of horse-power divided by weight, and no mechanism can alter the climb from this figure, but it may be obtained at low forward speed; hence the angle of the climb path may be much steeper for the same effective excess of horse-power per unit weight than for an aeroplane. The flying speed range also depends on the excess of power available, as greater power is required for horizontal flight both at very small and very great disc incidence; but the Autogyro has *no* stalling speed, and as the top speed increases the slow speed *decreases* with increasing margin of power. There will possibly be practical limits with extreme excess of power at both ends of the range.

The vertical nose dive is the same in principle as flying at high power with no disc incidence. Both cases seem beyond the range of what the Autogyro will be called on to do with any reasonable power margin.

In reply to Mr. Handley-Page, the torsion of the blade was a serious problem until a section was adopted (Göttingen 429) with fixed c.p. in the usual range of whirling incidence.

Mr. Hodgson's suggestion that rigid blades have advantages and would be required for large machines is entirely contrary to experience. The larger the blades the more necessary it is that the stress should be as nearly as possible pure tension.

Mr. Hodgson's test indicating several possible speeds is extremely interesting from the point of view of pure aerodynamical science, but it does not concern the performance of the Autogyro which maintains its own speed at small blade incidence under all conditions from 0° to 90° of disc incidence once it acquires sufficient angular speed.

Professor Bairstow's argument that the greater length of the blade path means greater drag loss for the same length of voyage must be modified by two

circumstances; first, the blades are at a better incidence for L/D; secondly, only a very small and clearly designed part of the whole is moving at these high speeds.

It would be rash to prophesy just what performance will be reached when competing designers have used every favourable circumstance and mitigated every adverse circumstance, but it may be confidently expected that detailed improvements will greatly increase every present advantage of the Autogyro tested at Farnborough.

PROCEEDINGS

FOURTH MEETING, FIRST HALF, 61ST SESSION

A joint meeting with the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, on Tuesday, November 3rd, Mr. Kerr Thomas presiding.

The PRESIDENT: This is a joint meeting of the Royal Aeronautical Society and the Institution of Automobile Engineers, and Sir Sefton Brancker has very kindly come here to support me. As it is a joint meeting we will dispense with the reading of the minutes, and I will ask Wing Commander Cave-Browne-Cave to read us his Paper on "The Evaporative Cooling of Aero Engines and the Condensation of Exhaust Gas for Water Recovery."

THE EVAPORATIVE COOLING OF AERO ENGINES AND THE CONDENSATION OF EXHAUST GAS FOR WATER RECOVERY

BY WING COMMANDER T. R. CAVE-BROWNE-CAVE, C.B.E., F.R.AE.S., A.M.I.MECH.E., A.M.I.N.A.

The engine cooling systems of almost all aircraft require a large radiator or a multiplicity of air-cooled fins to be exposed to the airstream with a consequent increase in drag, so large as to be a considerable fraction of the total drag of the aircraft. If the surface of the aircraft itself were used for dissipating the heat, a considerable improvement in performance might be effected.

In certain aircraft it is necessary to supply heat to the pilot, passengers, guns, etc., and for this purpose an electric generator driven by a windmill is employed and causes drag for the purpose of acquiring heat.

The heat which is to be dissipated from the engine is at a temperature quite sufficient for the purposes for which the electrical generator is supplying heat. The real difficulty lies in finding a reasonably light means of conveying the waste heat from the engine to the points where heat is required, or to the surfaces of the aircraft from which it can be dissipated without causing additional drag.

If a large amount of heat is to be conveyed by air, heated by an air-cooled engine, the weight and space required for trunks are prohibitive.

If water is used, the weight of water in the system would be great and the loss of water from a small leak is so rapid that the engine cooling system might be seriously impaired before the leaking part of the system could be shut off.

By far the lightest way of conveying heat is as the latent heat of steam.

If the rise of temperature of water passing through the engine is only some 20°F., as is now usual, the quantity of heat carried by 1lb. of water is 20 B.T.U. The heat carried by 1lb. of steam is 966 B.T.U. It is shown later in this lecture that, although the volume of the steam is relatively large, the pressure difference required to carry a given quantity of heat through a pipe or orifice of given size is, if dry steam is employed, only some 60 per cent. of that necessary if water with a temperature difference of 18°F. is the vehicle.

Mr. Ricardo has shown that the optimum temperature of an engine cylinder, so far as thermal and mechanical efficiency go, is probably intermediate between

those possible with a water-cooled and an air-cooled system. For that reason the use of cooling liquids with boiling points higher than that of water has been considered. It was claimed that evaporative cooling, perhaps under pressure, might have some advantage in this respect.

It was proposed that water at boiling point should be circulated round the engine. Steam formed was to be separated and condensed in a radiator which would return it, by gravity, as water to the system. There was, therefore, to be a continuous circuit of water all at boiling point and on this the steam condensing circuit would be a shunt.

One's experience with a water-cooled engine system when it boils is, however, not such as to cause engine designers to be at once enthusiastic about any evaporative system. It was generally thought that considerable alteration to the cylinder jackets and a different type of water pump would be necessary.

The problem of maintaining a sufficient circulation of cooling liquid could only be satisfactorily investigated by trial on an engine, and in 1921, when these views were discussed, a trial could not be arranged.

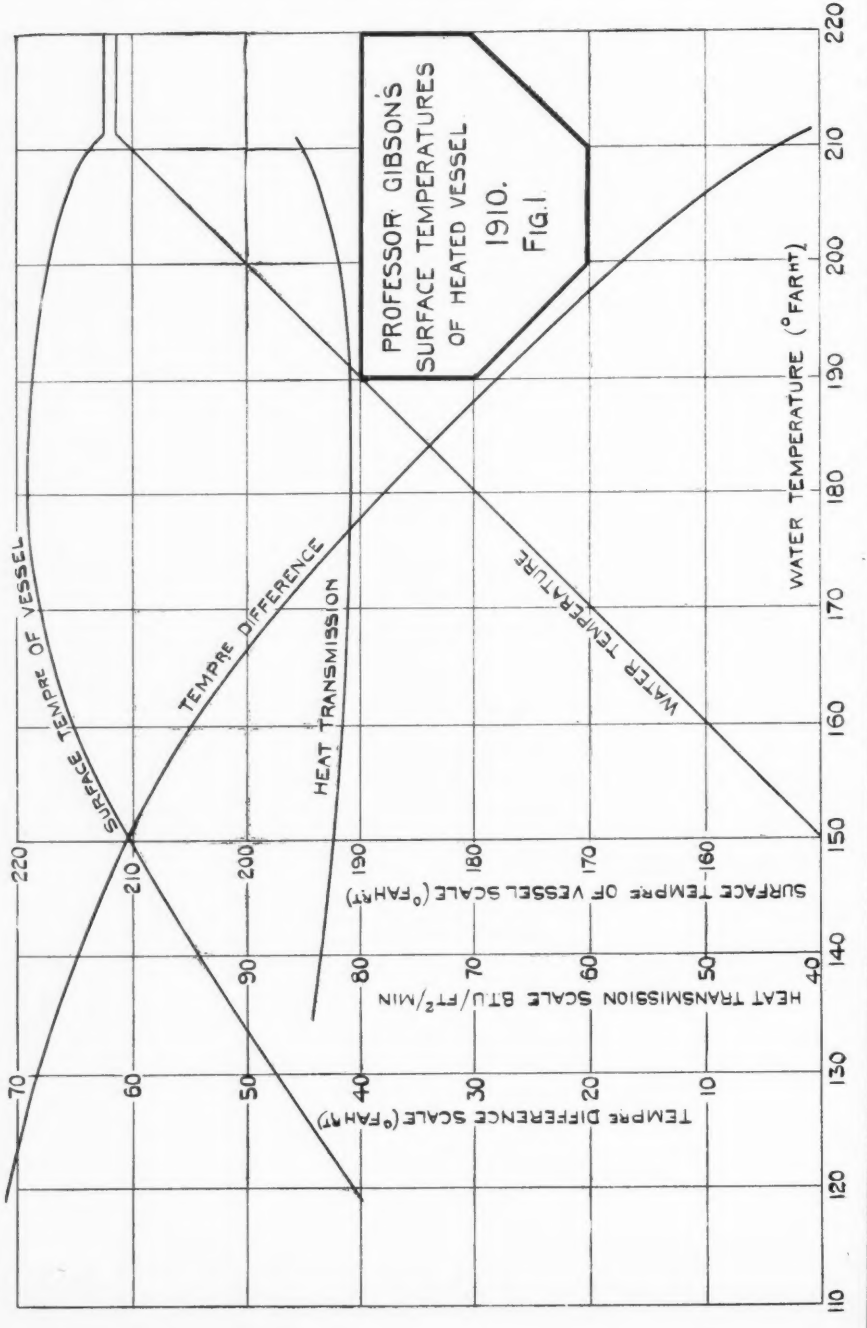
There still remained the question how the temperature of the strongly heated parts of the cylinder would be changed if water were actually evaporated at atmospheric pressure in the jackets. An opportunity for investigation arose later, and a search of published work which might give information on this point was made.

It was found that in 1910 Professor Gibson reported to the Institute of Engineers and Shipbuilders in Scotland some tests in which he had measured the surface temperatures of an iron vessel in which water was heated by a gas flame. The water was vigorously stirred during the experiment, but it was found that the temperature of the surface actually decreased as boiling point was reached. Fig. 1 has been prepared to show graphically, on a base of water temperature, the results he obtained. As the temperature of the water increased that of the vessel increased also. This continued only until the water had reached 180°F. After that there was a gradual decrease in the temperature of the vessel. The decrease became more rapid as the water approached boiling point, until finally the temperature of the vessel was only about a degree hotter than the water. Professor Gibson states that even at the highest rates of evaporation he could achieve in this apparatus, the difference of temperature between the water and the surface of the vessel did not exceed 1½°F.

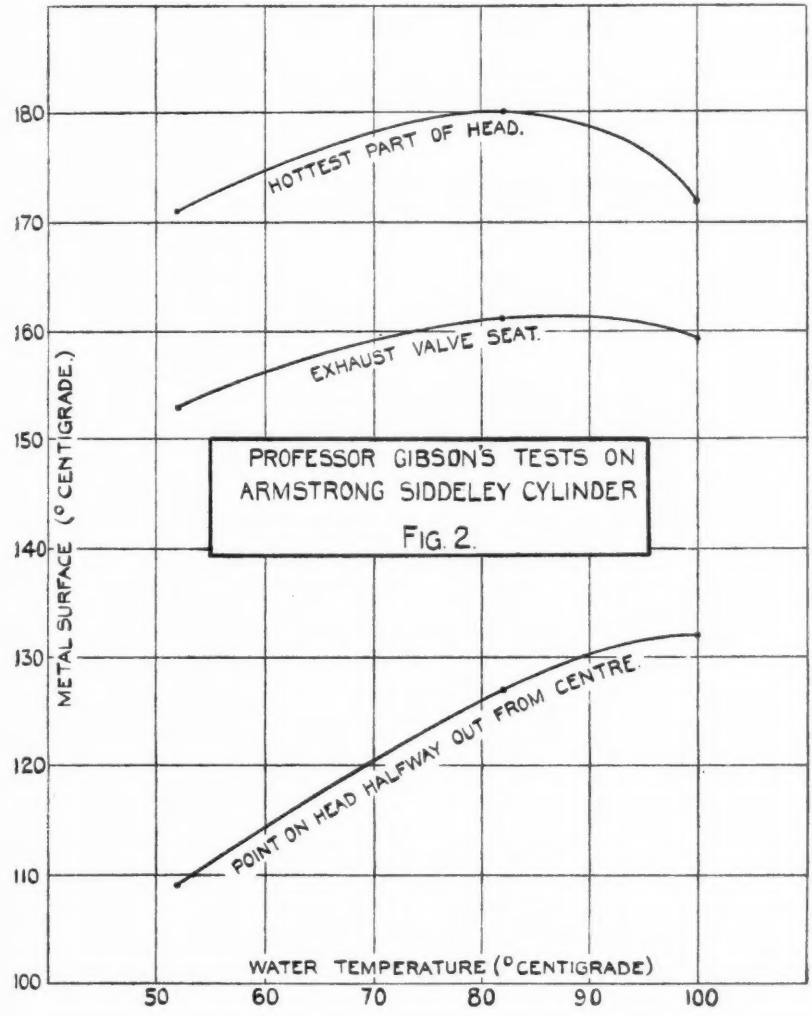
There was, as boiling point was approached, a corresponding increase in the rate of transmission of heat. The actual rate of transmission of heat quoted was, however, only some 85 B.T.U. sq. ft./minute, as compared with some ten times that value recently achieved in an evaporatively cooled Lion engine. It is doubtful whether this small temperature difference would not be considerably increased at the much higher rate of evaporation, but Professor Gibson's work indicates that when heat is being given to the vessel at a definite rate, the temperature of the metal will be less, when evaporation is taking place, than when the water is below boiling point.

Professor Gibson had reported to the Institute of Mechanical Engineers (December, 1923) some tests made on a water-cooled Armstrong Siddeley cylinder to determine the temperatures of various points on the cylinder head. He was asked to extend these tests to boiling water temperature. His results are shown in Fig. 2.

They indicate that, although the temperature of the comparatively cool part of the cylinder increases as boiling point is approached, the temperature of a point between the exhaust valve seats drops as the water begins to boil, while in the case of the hottest point in the cylinder head the drop is more pronounced.


PROFESSOR GIBSON'S
SURFACE TEMPERATURES
OF HEATED VESSEL
1910.
FIG. 1
SURFACE TEMPRE OF VESSEL
TEMPRE DIFFERENCE
HEAT TRANSMISSION
WATER TEMPERATURE
WATER TEMPERATURE (°FAHT)
SURFACE TEMPRE OF VESSEL SCALE (°FAHRT)
HEAT TRANSMISSION SCALE BTU/FT²/MIN
TEMPRE DIFFERENCE SCALE (°FAHRT)
110
120
130
140
150
160
170
180
190
200
210
220
40
50
60
70
80
90
10
20
30
40
50
60
70

There was, therefore, fairly clear indication that, provided a supply of water to all parts of the cylinder could be maintained, it was unlikely that any serious overheating would result from the evaporative system. It was more probable that the temperature of the colder parts of the cylinder would increase—thereby improving mechanical efficiency—while that of the hottest parts would be reduced.



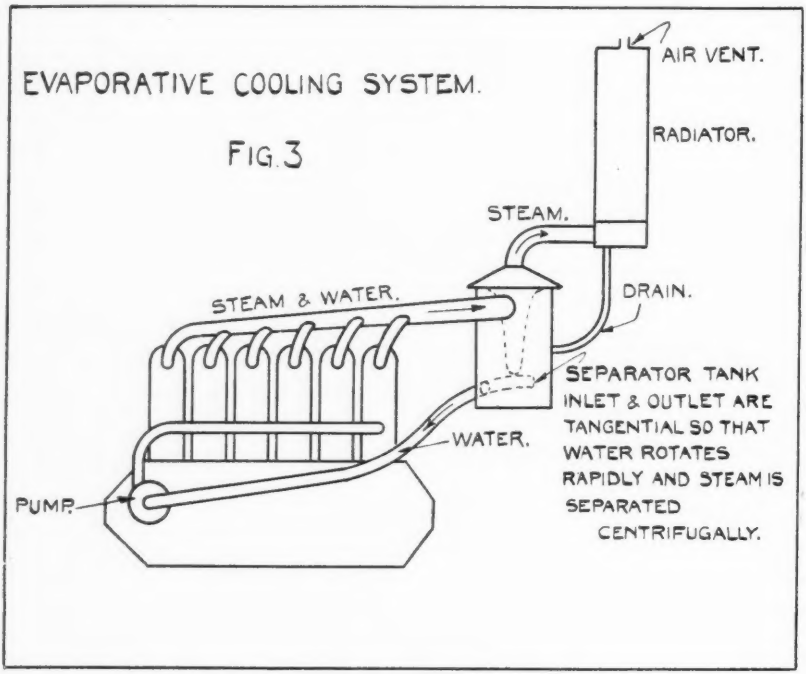
PROFESSOR GIBSON'S TESTS ON ARMSTRONG SIDDELEY CYLINDER

FIG. 2.

In 1924, when the design of Airship R.101 was started, it became evident that the necessary supply of heat to the passenger spaces could only be achieved for any reasonable weight if a steam system were employed. This steam could, of course, be evaporated in a special exhaust heated boiler, but this boiler was undesirable if steam could be obtained from the jackets. The potential advan-

tages were, therefore, very important. A 90 h.p. Rolls-Royce "Hawke" was arranged, as shown in Fig. 3. No alteration to the engine jackets or pump was made. The discharge orifice from each cylinder was unaltered, but the top water manifold was slightly increased. The external water and steam system was, however, made such that the steam could easily separate from the water.

The engine gave the same power and fuel consumption as with its usual system of cooling. It was stripped after some ten hours running and found in excellent condition. Since then it has done a large number of hours in other experimental work.



A large single cylinder unit constructed by Messrs. Beardmore has also been running regularly on evaporative cooling, without any defect or loss of power, which can be attributed to the evaporative system.

Steam formed when a water system boils cannot get down into the radiator and reach the cooling surface on which it will condense unless it forces out of the system an equivalent volume of water. Therefore, although the surfaces of the existing radiators would be quite sufficient to condense the steam if it reached them, this is not possible with the present usual arrangement.

It is generally recognised that in many aero engines there is considerable formation of steam in some parts while in others the water is not raised to boiling temperature. The water streams from all parts of the engine unit and the steam is condensed by water from cooler parts. The temperature of the water passing into the radiator may be below boiling point although in other parts of the system there may be a considerable volume of steam.

It is the formation of steam in this way which causes the discharge of a considerable quantity of water as the engine heats up to full working temperature; 1lb. of water occupies .016 cu. ft., but as steam 26 cu. ft. For one type of aero engine, of which the water jacket capacity is slightly under four gallons, an expansion tank of two gallons capacity is necessary to take the increase in volume caused by the formation of steam when the engine is running at full power with its ordinary water cooling system.

The water pump of an ordinary water system often decreases its output when the water approaches boiling temperature. The principal hydraulic resistance of such a system is in the radiator. The top of the radiator is at atmospheric pressure and, therefore, the pressure in the pump suction may be sufficiently below atmospheric to cause actual boiling at the temperature at which the water is returned.

In an evaporative system there is no hydraulic resistance of the radiator in the pump circuit. The pressure in the pump suction will be above atmospheric and boiling is therefore less likely, although the temperature is higher than in the water system.

It has often been suggested that an evaporatively cooled cylinder will be more liable to steam pockets than a water-cooled one. It is difficult to imagine a pocket which will be steam locked, but would not be air locked in a similar water-cooled system.

The area of flow required to convey a given quantity of heat with given loss of head appears to be considerably smaller for dry steam than for water.

Consider a duct through which H B.T.U. are to be passed per unit time. In a modern water-cooled engine the outlet temperature is assumed to be 10°C. (18°F.) above that of the inlet. The volume of water required to carry away H B.T.U. is therefore

$$H/(18 \times 62.5) \text{ ft.}^3 = .00089\, H \text{ ft.}^3$$

If the water enters at 212°F. and the whole of the heat is to be taken away by steam, the volume of steam necessary is

$$(H \times 26.37)/966 = .0273\, H \text{ ft.}^3$$

Assuming that the loss of head through a given passage is proportional to ρv^2

$$\frac{\text{Loss of head in steam}}{\text{Loss of head in water}} = \frac{(.038 \times (0273)^2)}{(62.5 \times (.00089)^2)} = .57$$

If there is a considerable amount of water passing through the duct in addition to the steam it is probable that the loss of head will be greater than that calculated above. It is interesting that the rate of evaporation is only about 1/5 that of lubricating oil circulation.

The water evaporated in the jackets of a 600 h.p. engine is about 1.44 gallons/min. and forms 370 cu. ft./min. of steam. The capacity of the centrifugal water pump of such a water-cooled engine is some 90 gallons/min. or 14.5 cu. ft./min.

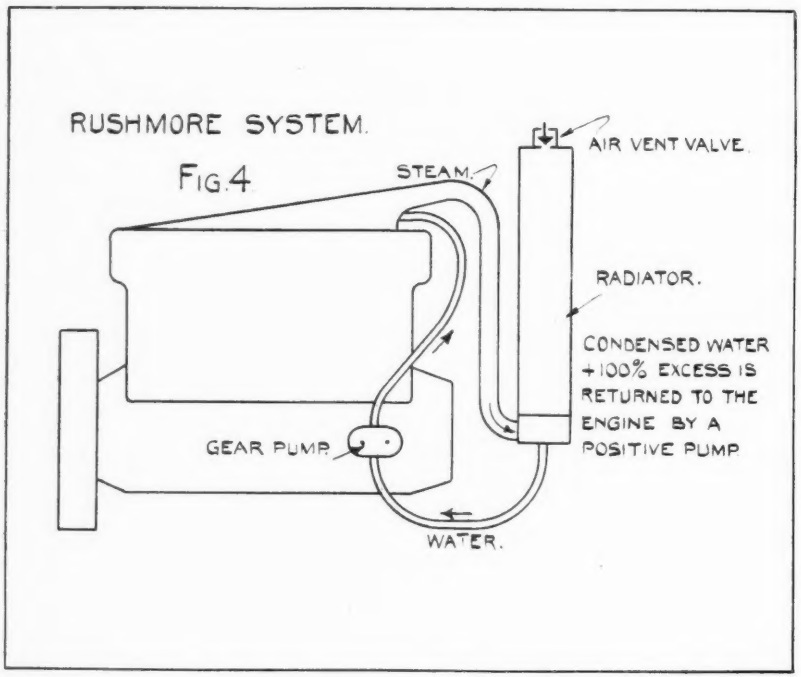
The speed of flow through the various passages is determined chiefly by the volume of steam. It is doubtful how much the presence of the large weight, but negligible volume, of water increases the resistance to flow. If we assume that the steam and water are discharged through a 3in. diameter pipe and that steam and water particles are moving at the same speed, 132 ft./sec., the h.p. in this issuing jet is 7.5 h.p., whereas if the steam were dry it would be only .115 h.p. The flow through the tortuous passages of the engine is too complex to deal with by similar calculation but is likely to lead to the same conclusions which may be summarised as follows:—

If the heat from a given space is to be removed by the evaporation of water,

the volume of steam formed is so great that the velocity of flow will be very high.

The resistance to flow of steam at this high velocity is greatly increased by the presence of liquid water.

The supply of water should therefore be restricted to that minimum which will ensure an adequate supply to all heated surfaces, or preferably the passages should be made so large that the steam and excess water can pass without excessive pressure drop. The latter arrangement appears the more likely to avoid shortage of water at any point.



The Rushmore system of evaporative cooling, Fig. 4, which is used on many American motor cars, is interesting in that there is no circulating pump comparable with the centrifugal pump of the usual system. A positive pump is employed to return the condensed water from the radiator to the engine, and its capacity is only about 100 per cent. in excess of the water actually condensed.

One of the advantages claimed for the Rushmore system, as applied to a motor car, is that the weight of the pump is greatly reduced.

Steam and Water Separator

If the radiator in which the steam is condensed is at a considerable distance from the engine it is desirable to separate from the steam the excess water which is carried through the engine. The separator is not required when the radiator is close to the engine or when the excess of water is small. No separator other than the bottom tank of the radiator is provided in the Rushmore system as applied to cars.

When an existing aero engine is changed to the evaporative system of cooling, it is probably desirable to retain the large capacity pump, at any rate until it is established that the circulation of water over the surfaces by convection is sufficient to remove the steam from the surfaces at the extremely high rate of evaporation without allowing them to become overheated. With this large excess of water a separator is probably desirable.

One satisfactory form of separator is a cylindrical tank into which the steam and water from the engine are introduced tangentially, the steam issuing from the centre of the top of the separator and the water tangentially at the bottom. The speed of rotation in such a tank is so high that there is great centrifugal separation.

A water level glass on the tank will not, when the water is in motion, indicate the quantity of water in the system. If such an indicator is required when running, it must either be connected to the pump suction and the steam discharge pipe or it may be desirable to use a form of separator in which the water is not rotating violently.

Condensing Radiators

One of the greatest advantages of the use of evaporative cooling in aircraft is that steam can be used to convey the waste heat to special panels arranged in the surfaces of the aircraft, from which heat can be dissipated with little, if any, increase in the drag. Alteration of an existing cooling system to use surfaces in this way, involves considerable novelty, and little work on these lines has been done until more is known of the possible troubles of the engine part of an evaporative system.

The use of a honeycomb radiator for condensing the steam has, therefore, been investigated because it is for the present, at any rate, more convenient to use that type than the surface radiator which is aerodynamically so much better.

Steam is discharged into the tank at the bottom of the radiator and forces its way upward through the honeycomb block condensing on the metal surfaces which are cooled by the flow of air outside. The condensed water flows down to the bottom tank and is returned to the engine system.

A vent is provided at the top of the radiator so that, as the supply of steam varies, the pressure will remain approximately that of the air outside.

The density of steam at atmospheric pressure is only .65 times that of air at the same temperature and pressure. Most of the air in the radiator will be at atmospheric temperature and therefore even more dense than that air immediately above the steam.

Consider the flow of steam upward through a radiator of rectangular face. The velocity of flow decreases as the steam rises and the volume is decreased by condensation. A particle of air which has entered the steam space will therefore be swept upwards until the flow of steam becomes insufficient to resist the greater weight of the particle of air.

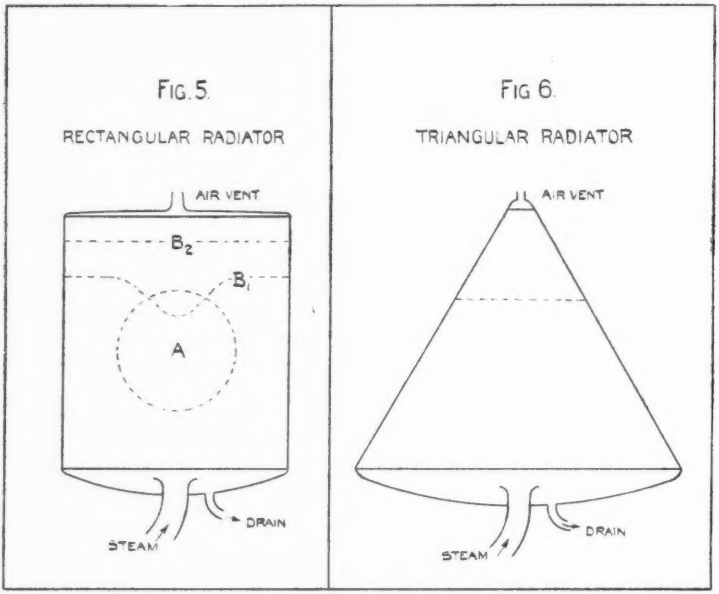
The line of separation B between steam and air will therefore, as a whole, rise and fall as the supply of steam varies.

If, however, the steam flow to one part of the radiator is less or the rate of condensation there is greater, the steam air boundary will sink down locally, as at B_1, Fig. 5. The steam speed at the side of the pocket will increase by reason of the decreased area of flow and the boundary above it will be carried higher. The flow will then close in and a pocket A will be formed.

Steam will then be flowing radially inwards towards the centre of A and opposing the escape of any air from the pocket, which therefore becomes dead surface and cannot be brought into action by any increase of the supply of steam.

The first steam radiator we tried was a rectangular one. A large pocket extending over some 30 per cent. of the total face area formed and did not decrease appreciably in size even when the steam supply was increased sufficiently to blow steam out of the vent. As the effect explained above was not at the time appreciated, the cause of the pocket remained obscure until a small hole was made in the honeycomb at the centre of the pocket. The air escaped and the whole surface became effective.

The radiator should therefore be so shaped that the area for steam flow



decreases as the quantity of steam is decreased by condensation. The steam speed will then be maintained until condensation is complete. The simplest form of radiator to meet this requirement is a circular one with steam supplied round the whole periphery flowing radially towards a single central vent.

If such a radiator were used in freezing air and not entirely filled with steam, water condensed in the upper semi-circle would run down on to colder surfaces and freeze. It is desirable, therefore, to use only the lower semi-circle in which condensed water flows down over hot surfaces.

For convenience of construction only a 60° sector was used for the next experimental radiator, Fig. 6. Steam was supplied at the base. The sides of the block were carefully sealed to prevent the passage of steam between the block and the side plates.

With this construction the boundary between steam and air is very sharply defined and rises and falls according to the variation of steam supply, always remaining parallel to the surface by which steam enters.

The temperature of a steam radiator when filled to its full capacity is uniform and somewhat higher than the mean temperature of a water filled radiator. The drop of temperature in a modern aircraft radiator is, however, so small that the

increase in mean temperature is not quite sufficient to neutralise a small deficiency due presumably to small traces of air in the steam space.

R.A.E. Report B.A. 539 gives the results of accurate wind channel tests on a triangular radiator of the type described and compares them with those of a water-filled radiator. In an appendix to that report the equilibrium of the boundary between steam and air is examined mathematically.

There are various patent specifications which propose to overcome the formation of air pockets by dividing the rectangular radiator block into vertical radiators, each of which is sealed at the top except for a hole into the top tank space sufficient to allow air to pass in and out as necessary, but small enough to prevent steam which has passed through one section passing down into another section and trapping air there. We have not tried this system because it introduces certain constructional difficulties in an aircraft radiator which do not occur in the radial flow type which appears to achieve this object by maintaining a high steam speed right up to the boundary.

Suggested Conclusions

We are at present only in the early stages of the investigation of evaporative cooling. Theories and conclusions, in so far as any have been reached, are put forward with reserve.

It is suggested that:—

Evaporative cooling will have no important influence on the running of an aero engine, provided an adequate supply of water to all parts of the cylinder head, etc., can be maintained. The sufficiency of this supply in any particular engine can, at present, only be ascertained by actual trial, but no trouble appears probable provided the passages for flow are reasonably large.

The use of steam as a vehicle to convey waste heat to parts of the surface of the aircraft offers a means of reducing greatly the drag now involved in radiators to dissipate this heat.

When using a honeycomb radiator there is no appreciable change in efficiency caused by the use of steam.

The engine will warm up more quickly on starting and will cool down less quickly during a long glide.

At very high altitude an evaporative system may have some advantage from being able to maintain the full boiling temperature corresponding to the surrounding pressure. The boiling temperatures corresponding to heights of 10,000, 20,000 and 30,000 ft. are 90°, 80° and 70°C. respectively, many parts of a water-cooled system will be considerably below these temperatures and therefore undesirably cold.

A steam radiator will probably be immune from freezing. The engine cannot be overcooled when throttled. Radiator shutters, to be worked by an automatic device, or worse still by the pilot, are not required.

The loss of water through a leak or when flying through abnormally hot air will not be so rapid as with a water system.

The weight of water in an evaporative system is considerably less than in a water-cooled system.

Steam appears to be by far the lightest means of heating the passenger space and cooking. It may be possible to supply such a generous amount of heat to the pilot's cockpit as greatly to increase his comfort and decrease the weight of special clothing.

For use in a motor car it is claimed that, particularly when starting or running throttled, the greater temperature of colder parts of the engine greatly

reduces piston friction and makes an important decrease in the leakage of fuel past the pistons and the consequent "crankcase dilution." It would be interesting to know how far this reduction of dilution is an engineer's—as distinct from a salesman's—improvement.

The lecture is in many respects premature and lacking in detail of achievement or even in description of the work actually in progress. It may, however, be sufficient to produce constructive criticism which will be of great value to us and also to persuade engine designers to investigate the very small changes which would make their new engines suitable for evaporative cooling, thereby rendering possible the various advantages which appear, so far as aircraft are concerned, to be of considerable value if they can be achieved without sacrifice of engine reliability and performance.

WATER RECOVERY BY CONDENSATION OF EXHAUST GAS

Water recovery appears at first sight to be of interest limited almost entirely to large airships, but in the course of our investigations we have come across certain points which may have wider interest in connection with exhaust heat boilers and similar problems certain to become of more general interest as the use of internal combustion engines extends. There appears to be very little published detail description of exhaust gas boilers, and it is hoped that the particulars and conclusions discussed here, even if of little assistance to those engaged on exhaust gas boiler design, may call forth criticism which may be useful to us.

It is proposed to discuss some fundamental considerations connected with the cooling of exhaust gas and to indicate the factors which limit the quantity of water recoverable under various conditions. The chief difficulties which we have encountered will be described, but it is not desirable to describe in detail the apparatus we are now developing because others might be tempted to flatter us in the most sincere way, rather than bring their talent to bear on the problem independently—heuristically—thereby greatly increasing the likelihood that someone will attain our common object, the evolution of a thoroughly satisfactory system.

Reason for Water Recovery

The object of water recovery is to compensate the loss of weight in an airship as fuel is consumed.

Although it is possible to fly an airship which has considerable positive or negative buoyancy it is not safe to land her or bring her to a mooring mast unless her weight is correctly adjusted to her buoyancy, *i.e.*, to the weight of air she displaces.

The weight of the water recovery apparatus will no doubt be considerable, but is probably justified by the reduction which can be made in the quantity of water ballast carried. Ballast in considerable quantity is not required immediately after leaving the mast, but considerably later in the flight when comparatively unexpected meteorological conditions may be met. By that time sufficient water to meet the requirement for ballast will have been recovered.

In the flight to Egypt R.101 will burn some 25 tons of fuel oil. She will leave in approximate static equilibrium and if during the passage she has neither discharged gas nor acquired weight by some means, she will arrive some 25 tons light. To restore equilibrium before landing she must discharge some 823,000 cu. ft. of gas which will cost some £600 to replace before she continues her journey.

The description of the water recovery apparatus prepared for Rigid Airship No. 1, and tried in October, 1910, points out that the apparatus will avoid the following disadvantages, of which the third is considered the most serious:—

(1) Expense of gas let out to preserve equilibrium.

(2) Loss of speed on extended flights due to the use of dynamical means to preserve equilibrium by day and night (the gas being let out so as to preserve the mean buoyancy correct).

(3) Strategic handicap, in that an airship wishing to take fresh fuel from a secondary base, such as a ship, must at the same time take in an equivalent amount of gas.

Water Formed

In the combustion of a hydro-carbon fuel, a weight of water equal to nine times the weight of hydrogen in the fuel is formed. If part of this water can be condensed and collected, the weight so acquired will tend to reduce the amount of gas which must be discharged to restore equilibrium.

The water formed by the combustion of 1lb. of fuel depends upon the hydrogen content. Aviation petrol contains 15 per cent. hydrogen by weight, while heavy oil contains from 13½ per cent. to 13 per cent. of hydrogen, the latter content being assumed in the following calculations.

Therefore the water formed by the combustion of

1lb. petrol containing 15 per cent. hydrogen is 1.35lbs.
1lb. fuel oil containing 13 per cent. hydrogen is 1.17lbs.

Quantity of Air Used

The air chemically necessary for the combustion of 1lb. of each of these fuels is 15.3lbs. and 14.8lbs. respectively. It is found that a petrol engine, when developing full power, burns about 10 per cent. less, and at the power corresponding to maximum economy, some 10 per cent. more, than the chemical equivalent.

The heavy oil engine requires 30 per cent. excess air at full power while at the power corresponding to maximum economy twice this amount of air is required.

Therefore the air required with 1lb. of fuel is

Petrol engine at full power	13.8lbs.
At maximum economy	16.8lbs.
Compression ignition engine at full power	19lbs.
At maximum economy	38lbs.

Water Available for Recovery

The air which enters the engine will contain a quantity of water which depends on its pressure, temperature and relative humidity, and therefore varies greatly according to the conditions around the airship. The weight of water thus entering the engine varies from almost zero to 10 per cent. or sometimes 20 per cent. of the fuel weight.

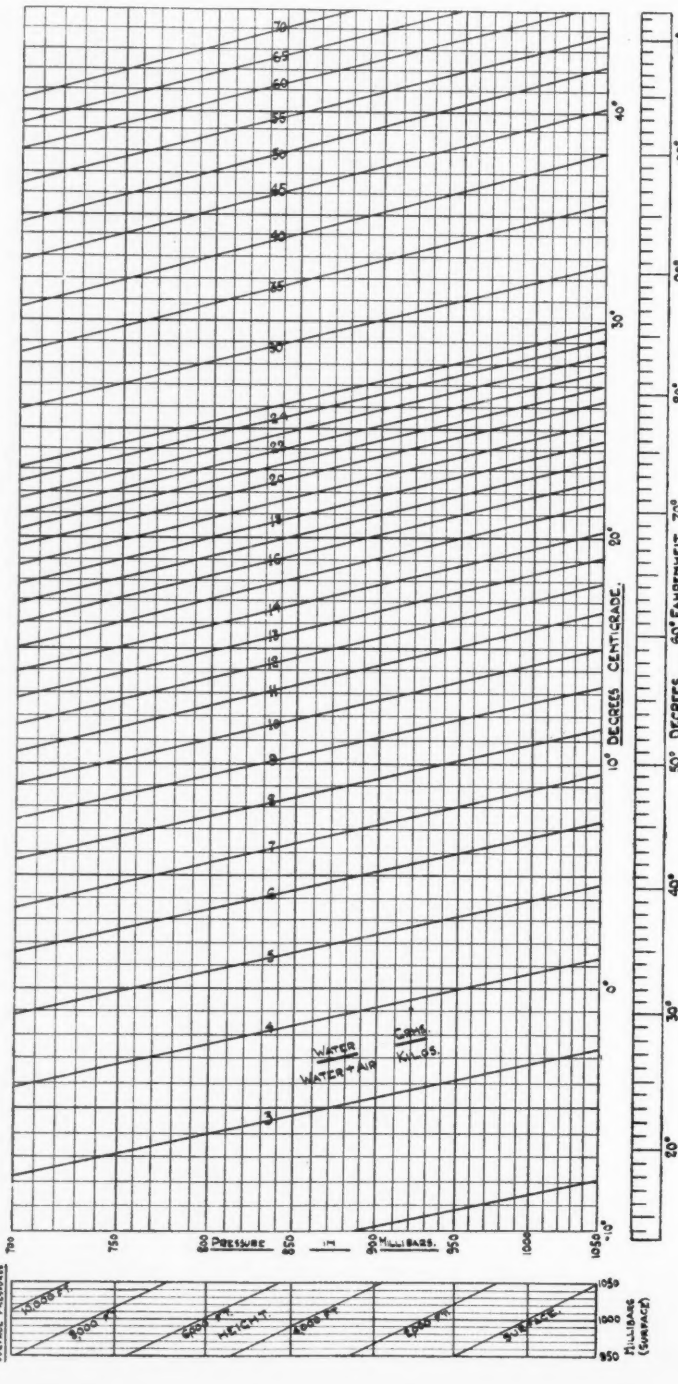
The exhaust gas leaves the engine at some 900°C., containing, as highly superheated steam, the water which entered the engine with the air and the water formed by combustion.

If the gas is cooled, no water will condense until a temperature is reached at which the quantity of water present is sufficient to saturate the gas. Further cooling increases the quantity of water condensed. If the mixture is passed through a separator which collects all the particles of liquid water, the gas

FIG. 1.

MODIFIED HERTZ DIAGRAM.

MOISTURE CONTENT FOR VARIOUS CONDITIONS.



will leave the apparatus saturated and carrying with it a quantity of water of saturation which cannot by any reasonable means be separated from it. The water of saturation in the issuing gas is lost, and its quantity depends upon the temperature and pressure at which the gas passes through the separator and is released.

The quantity of water which can be recovered, therefore, depends very greatly on the atmospheric conditions in which the airship is flying, and it will be shown later that, by selecting the height at which to fly, the pilot can make a difference between being able to recover 60 per cent. of his fuel weight and being unable to collect any water at all or, in another case, between 100 per cent. and 70 per cent. recovery.

Calculation of Water Available

To calculate the water recoverable in a given set of atmospheric conditions is a very laborious task, and one which the pilot could not possibly carry out in flight, even if he knew the distribution of temperature and density.

The Hertz diagram which is used for meteorological purposes gives the moisture content of air under various conditions. Parts of this diagram have been used and its range somewhat extended to give Fig. 1.

The use of this diagram involves the assumption that the density of the gas is equal to that of air. Actually it may be as much as 4 per cent. greater, depending on the proportion of excess air used. The error is not however important, as we require a comparison between values subject to the same correction and in which the range of variation is very large.

The diagram is graduated logarithmically with abscissæ representing temperature and ordinates atmospheric pressure in millibars. The diagonal lines represent the moisture content in saturated air as the ratio water/(water + air) given in grammes/kilogrammes, *e.g.*, the point corresponding to 900 millibars and a temperature of 10°C. lies at .4 of the distance between saturation lines 8 and 9. Saturated air under these conditions, therefore, contains 8.4 gms. of water in 1 kilo of saturated air.

Tables 2, 3, 4, 5, have been selected from a number prepared at the Air Ministry to show the variation of water recovery theoretically possible under various conditions.

It has been assumed that the airship carries water recovery apparatus capable of cooling the exhaust gas to within 10°C. of whatever may be the surrounding atmospheric temperature and with a separator which will collect all moisture actually condensed at this temperature.

Columns 1, 2, 3, 4 and 5 give the observed meteorological data.
Column 6 gives the water content, W_1, of the incoming air, if saturated.
Column 7 gives the actual water content, W_2, corrected for relative humidity.
Column 8 gives the water content, W_3, of saturated air at the assumed temperature of discharge, *i.e.*, 10°C. above the inlet temperature.
Column 9 gives W_4, the difference between columns 7 and 8 and therefore the water which must be added to the inlet air to saturate it at the discharge temperature.

When burning 1lb. of heavy oil which produces 1.17lbs. of water and uses 19lbs. of air at full power and 38lbs. of air at half power, the water recovered will be :—

At full power $W_5 = 1.17 - 19\ W_4$ lbs. water per lb. fuel burnt.
At half power $W_6 = 1.17 - 38\ W_4$,, ,, ,,

These are given in columns 10 and 11 respectively and form the basis of comparison desired.

TABLE 2.

1	2	3	4	5	6	7	8	9	10	11
Height above M.S.L.	Pressure.	Temperature.	Temperature.	Relative Humidity.	Water Content at Saturation.	Actual Water Content.	Water Content for Saturation at $(T+10)°C$.	Additional Water Required.	Water Recovered at Full Power $W_5 = 1.17 - 19\ W_4$.	Water Recovered at Half Power $W_6 = 1.17 - 38\ W_4$.
H	P	T	T	R.H.	W_1	W_2	W_3	W_4	W_5	W_6
feet	m.b.s.	°C.	°F.	%						

ENGLAND (ANDOVER).

Dec. 7th, 1922, 14.15 G.M.T. Aeroplane ascent.

NOTE.—Stratus cloud 3500 to 4000 feet with inversion of temperature above and decrease of humidity though not to a very low value.

H	P	T(C)	T(F)	R.H.	W_1	W_2	W_3	W_4	W_5	W_6
2040	950	3.6	38.5	98	.0052	.0046	.0101	.005	1.05	.95
3470	900	1.1	34	100	46	46	.0090	44	1.10	1.00
5000	850	2.5	36.5	87	53	46	.0105	59	1.05	.95
6600	800	2.2	36	80	55	44	108	64	1.05	.95
8320	750	1.7	35	69	57	39	112	73	1.05	.90
10140	700	—0.3	31.5	80	53	42	104	62	1.05	.95

TABLE 3.

ATLANTIC (S.W. OF CANARIES) (26° 0′ N., 24° 38′ W.).

Sept. 10th, 1907, morning. Ballon sonde ascent from ship.

NOTE.—Low inversion over the ocean with very dry air above.

H	P	T(C)	T(F)	R.H.	W_1	W_2	W_3	W_4	W_5	W_6
16	1019	23.8	75	87	.0179	.0156	.0340	.0184	.80	.45
1120	980	22.3	72	81	170	138	316	178	.85	.50
1640	961	23.1	73.5	56	183	102	334	232	.75	.30
2591	931	23.4	74	37	191	.0071	350	279	.65	.10
3280	908	23.3	74	33	195	64	370	306	.60	.00
4920	858	20.0	68	32	167	53	320	267	.65	.15
6560	808	17.1	63	31	149	46	280	234	.70	.30
8200	761	13.4	56	31	125	39	204	195	.80	.45
9840	717	9.1	48	34	.0098	34	190	156	.85	.60

TABLE 4.

EGYPT (HELWAN).

Sept. 16th, 1924, early morning. Aeroplane ascent.

NOTE.—Cloud from about 1600 to 3000ft. (presumably detached cloud) with inversion and very dry air above. Conditions at mid-day as shown in next table.

H	P	T(C)	T(F)	R.H.	W_1	W_2	W_3	W_4	W_5	W_6
1760	950	21.7	71	73	.0167	.0122	.0315	.0193	.80	.45
3270	900	18.9	66	67	149	.0099	284	185	.80	.45
4900	850	21.7	71	30	189	46	370	324	.55	.00
6590	800	17.2	63	31	151	47	283	236	.70	.25
8380	750	12.8	55	41	121	50	230	180	.85	.50
10300	700	11.7	53	45	121	54	230	176	.85	.50

TABLE 5.

EGYPT (HELWAN).

Dec. 9th, 1924, early morning. Aeroplane ascent.

NOTE.—A winter ascent in Egypt. No cloud below 10,000 feet on this occasion.

H	P	T(C)	T(F)	R.H.	W_1	W_2	W_3	W_4	W_5	W_6
1840	950	15.0	59	63	.0109	.0069	.0204	.0135	.90	.65
3330	900	13.3	56	57	104	59	196	137	.90	.65
4900	850	10.6	51	44	.0091	40	176	136	.90	.65
6550	800	8.9	48	53	87	46	167	121	.95	.70
8300	750	5.6	42	43	75	32	145	113	.95	.75
10140	700	1.7	35	56	61	34	120	.0086	1.00	.85

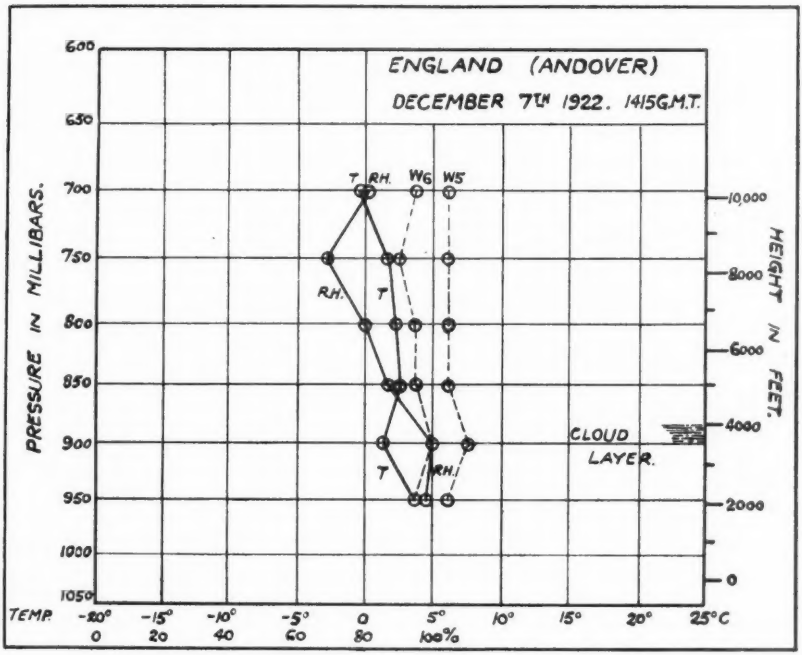
Variation of Recovery with Atmospheric Conditions

Figs. 2, 3, 4 and 5 show graphically the temperature and humidity of the air and the theoretical maximum recovery at full and half power. These are plotted as abscissæ against ordinates of actual height.

The curves show how greatly the possible recovery depends upon the height at which the pilot decides to fly.

The many cases which have been examined in this way lead to the following general conclusions which may guide a pilot if he knows the approximate distribution of temperature in his neighbourhood.

FIGURE 2.



Immediately above an inversion of temperature is usually the region where recovery will be a minimum. It is unfortunate that this region immediately above an inversion is that in which it is easiest to fly steadily. Recovery is usually a maximum close beneath an inversion. The air here is usually turbulent and it is an uncomfortable area in which to fly.

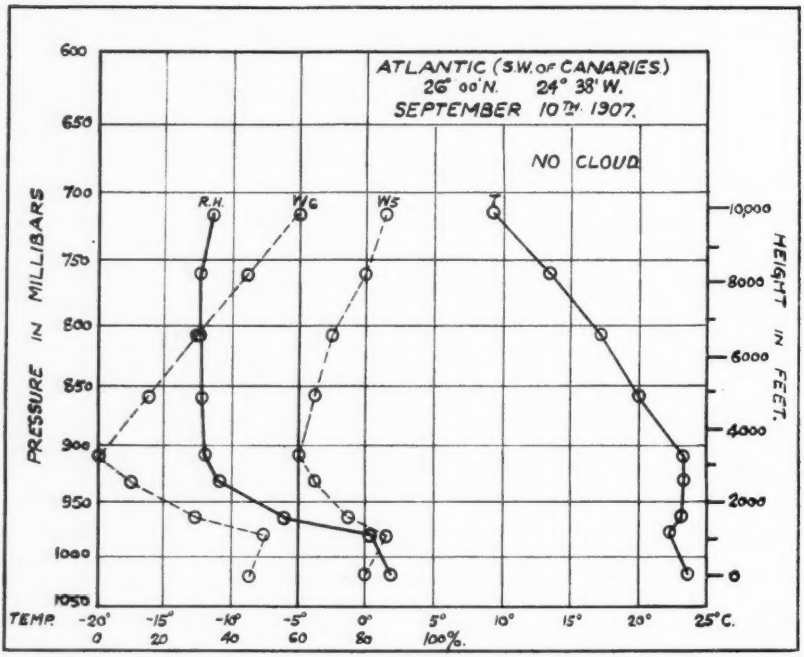
Except for these usually definite maxima and minima near an inversion, recovery will usually improve with increase of height.

The results show that it will frequently be impossible to recover 100 per cent. of the weight of fuel burnt even with the very effective apparatus that has been assumed. Unless at other times in the flight it is possible to recover more than 100 per cent., the airship will gradually become light and, in order to restore equilibrium, gas must be discharged.

If this gas is burnt in the engine the energy derived from it will not only reduce the consumption of liquid fuel, but will greatly improve the water recovery. If any water is being recovered, the gas finally leaving the airship must be at least saturated. It appears reasonable to assume that if hydrogen is burnt in the engine the increase in water of combustion will all be recovered, because the presence of a greater quantity of water should not increase the moisture content of the gas leaving the separator.

If on a certain passage it is found that, although 25 tons of oil have been burnt, only 15 tons of water have been recovered, 330,000 cu. ft. of hydrogen

FIGURE 3.



must be discharged to restore equilibrium; 190,000 cu. ft., however, if used in the engine, and the water recovered, would be sufficient; a saving of 140,000 cu. ft. of gas, equivalent to say £100. This takes no account of the power derived from the hydrogen which will reduce the consumption of liquid fuel and also the hydrogen which must be expended to restore equilibrium.

Quantity of Heat to be Dissipated

The quantity of heat which must be abstracted from the exhaust from 1lb. of fuel with 30 per cent. excess air is shown on Fig. 6, Curve 1. The water which can theoretically be recovered by cooling to various temperatures is also shown, Curve 2. The latter curve demonstrates how necessary it is to continue the cooling to the lowest temperature possible. The great increase in cooling area necessary to achieve the lower temperature cooling is shown by Curve 3 of

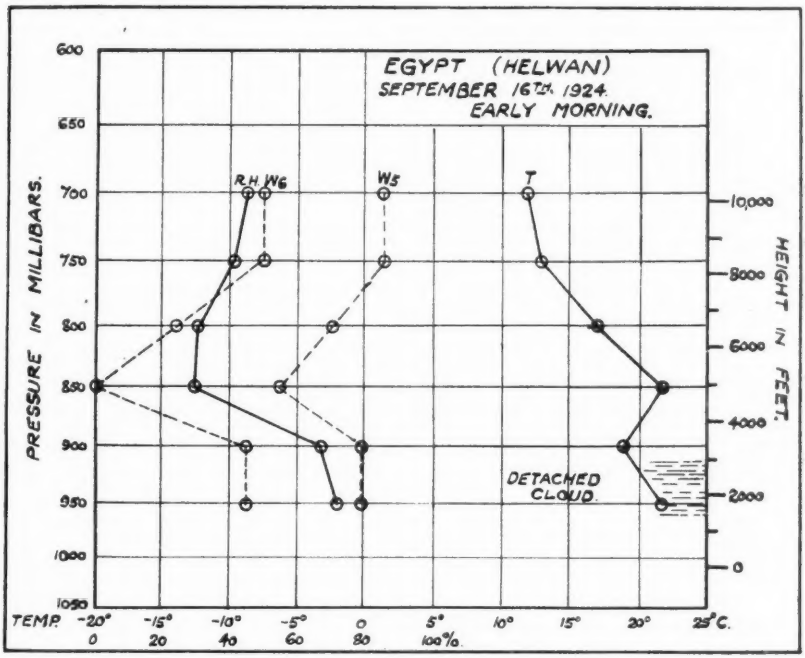
which the ordinate at any temperature is proportional to the area of the duct required to cool the gas from 900°C. to that temperature.

Of the total area necessary to cool the gas to within 10°C. of the external air only 23 per cent. contains gas at more than 100°C.

Relative Merits of Cooling by Air or Water

If it is considered necessary to use some of the heat of the exhaust gas for the generation of steam for auxiliary purposes, a part of the exhaust duct must be water-cooled. Such an arrangement has the advantage that hot air-cooled exhaust pipes are avoided. There are, however, several disadvantages. As it

FIGURE 4.



may not always be necessary to use the steam from this water-cooled portion of the duct, extra radiator capacity in which the steam can be condensed when not otherwise required, must be provided.

The area of surface required to cool the hot exhaust gas is, of course, much less in a water-cooled than in an air-cooled system, but the area required for condensing the steam totally outweighs this advantage. Steam cooling can only be continued down to a gas temperature of, say, 120°C. To cool below that temperature by means of water would involve not only enormous areas both for the transfer of heat to and from the water, but also enormous weights.

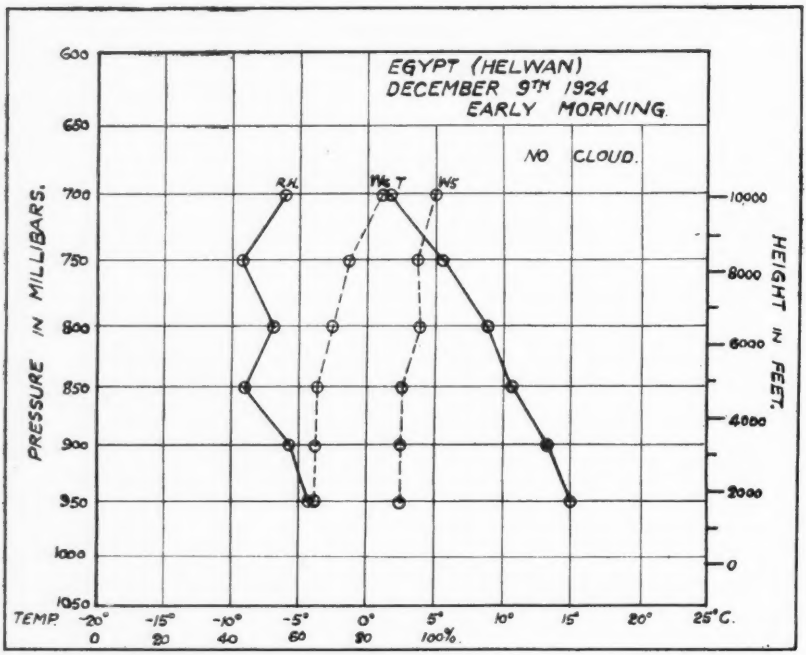
Assuming that below 120°C. the cooling is to be by air, a comparison was made of the surface required to cool the gas from 900°C. to 120°C. by air at 0°C. direct and by the evaporation and recondensation of water.

On assumptions which are probably satisfactory for comparative purposes, it was calculated that the area required for

	Comparative Areas. Air 0°C		Air 38°C.	
Cooling the gas in an air-cooled duct	6		7·3	
Cooling gas in a water-cooled duct	3·7	19·7	3·7	29
Condensing the steam in an air-cooled condenser	16		25.2	

With this enormous difference of area in favour of air cooling must be considered the weight of a water-cooled and condensing system per unit area. The advantage of direct air cooling is therefore overwhelming, unless steam-generated by exhaust heat is required for some auxiliary purpose, or unless an air-cooled exhaust pipe surface at high temperature is not permissible.

FIGURE 5.



Proportions of the Cooling Duct

The design of the cooling duct involves a compromise between two considerations, (1) the amount of cooling area must be small, (2) it is desirable to impose on the exhaust the minimum pressure in excess of that at the engine inlet.

The rate of dissipation of heat through unit area of the duct varies as the difference of temperature between gas and air, also on the speed of gas and external air over the surface of the duct. The exhaust pressure controls the speed of the gas flow through a duct of given dimensions.

Mr. Glauert, in R.A.E. Report B.A. 543, has examined this problem mathematically and shown that the optimum is reached when the area for gas flow is constant along the duct and is such as will take the exhaust gas from the

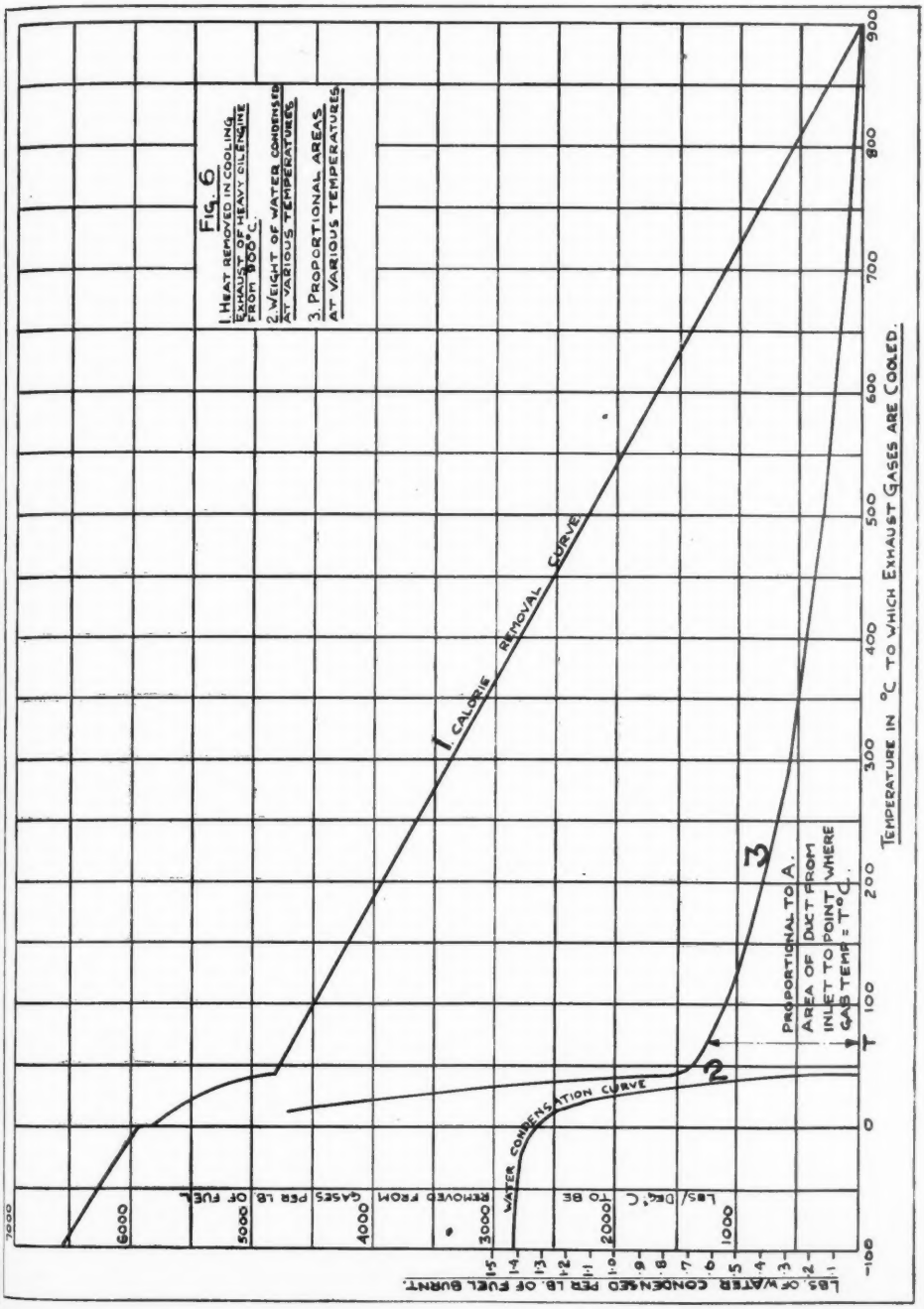


Fig. 6
1. Heat removed in cooling exhaust of heavy oil engine from 900°C.
2. Weight of water condensed at various temperatures.
3. Proportional areas at various temperatures.
1. Calorie removal curve
2
3
Water condensation curve
Proportional to A.
Area of duct from inlet to point where gas temp = T°C.
Temperature in °C to which exhaust gases are cooled.
Lbs. of water condensed per lb. of fuel burnt.
Lbs./deg. C to be removed from gases per lb. of fuel.
-100
0
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1

engine, when cooled to atmospheric temperature, at the same speed as that of the external air over the surface of the duct. If the duct is of rectangular section the ratio of the sides should be large.

The actual dimensions depend on assumptions as to the transfer of heat to and from the duct, the limits of back pressure and the permissible length of the duct, but the general conclusions quoted above are of considerable value in designing any system.

Exhaust Gas Boiler

According to the original intention, steam from the exhaust was required for an auxiliary purpose and experiment was therefore made to determine the best water-cooled apparatus in which to do the iritial stages of cooling.

Dr. Stanton has shown that the transfer of heat from a hot tube to air flowing through it with velocity V is proportional to $V^{0.7}$.

Presumably the same relation holds good for the transfer of heat from gas to the tube.

Squadron Leader de Courcey made some tests at Cambridge to determine the flow of heat from the exhaust gas of a petrol engine to a straight water-cooled exhaust pipe. His results were specially interesting because they extended to gas speeds of 800 ft./sec., considerably higher than any to which reference in similar experiments was found. His work, which will shortly be published, confirmed the importance of high gas speed as shown by Stanton's formula and also indicated that at these very high gas speeds there was no appreciable deposit of carbon or oil after the first very slight blackening.

These considerations led to an exhaust boiler which may be interesting to describe.

The important respect in which exhaust gas differs from the gases in an ordinary steam boiler is that, whereas in the latter there is seldom as much as $\frac{1}{4}$lb./in.^{2} difference of pressure to drive the gas through the boiler, the pressure in the exhaust manifold of an internal combustion engine can be raised to 1 or perhaps 2lbs./in.^{2} without appreciably detracting from the performance of the engine. If full advantage is taken of this relatively high pressure to produce high gas speeds, the heat transmission per unit of heating surface can be considerably improved.

In order to prevent the passage of a hot core of gas through the tubes, baffles were used. A tube of smaller diameter than the water-cooled pipe was pinched in dies in alternate planes at right angles. The dies were so shaped that at the edges of the flattened area the baffle tube fitted the water-cooled pipe accurately. The ends of the baffle tube were closed as shown in Fig. 7. The area left between the tube and the baffle for the flow of gas depended on the diameter of tube from which the baffle was made.

This area of flow changed gradually from section to section so that there was little resistance to gas flow even at high speeds, and no large eddy spaces in which fouling would deposit.

The flattened baffle tube was made a tight fit in its pipe and as it became hotter than the pipe, pressure between these areas of contact was considerable and the heat given by the gas to the baffle passed through these areas of contact to the water-cooled tube. The deposit of dirt on these tubes and baffles was small, but as when the pipe was cold it was easy to withdraw the baffle, there was no difficulty in cleaning the surface of both pipe and baffle. Baffles of this type were tried on the exhaust of a 90 h.p. Rolls' "Hawke," but accurate measurements of gas flow, temperature and rate of evaporation were not made before it was decided that steam generated by exhaust heat would not be required, and our efforts were concentrated on the direct air-cooled system.

Cooling and Separation Under Pressure

It has been suggested that the cooling apparatus should be maintained at considerable pressure or that the exhaust gas should be recompressed at a certain stage and the condensed water separated either at the high pressure or after the gas has been re-expanded adiabatically to atmospheric pressure. A considerable gain in recovery can theoretically be made in this way.

If saturated air at, say 10°C., is compressed to 2, 3 or 4 atmospheres pressure and again cooled to 10°C., $\frac{1}{2}$, $\frac{2}{3}$ and $\frac{3}{4}$ respectively of the amount of moisture it contained will be liquefied and can be separated. The saturated air, if expanded adiabatically, will be so greatly cooled that it will liquefy a further small quantity of moisture. It may not be necessary to compress and expand the whole of the exhaust gas in this way, because if part is so treated the remainder may be cooled below atmospheric temperature by the very cold gas leaving the expansion chamber.

Apart from the weight of the compressor and the energy required to supply the difference in work of compression and expansion, a greater difficulty is encountered in the cooling surfaces which must be made capable of withstanding internal pressure. We have seen what a large proportion of the total heating surface is required for the final stages of cooling, and to make these large surfaces capable of maintaining considerable internal pressure, involves great increase of weight and complexity. The same difficulty applies to a system in which part of the gas is cooled below atmospheric temperature by other gas which has been compressed and re-expanded as described above.

This very cold re-expanded gas must be kept separate from the saturated gas it is to cool, because if they mix, much of the water condensed from the uncompressed gas will be taken up in re-saturating the cold gas which has passed through the compressor.

Early Forms of Water Recovery Apparatus

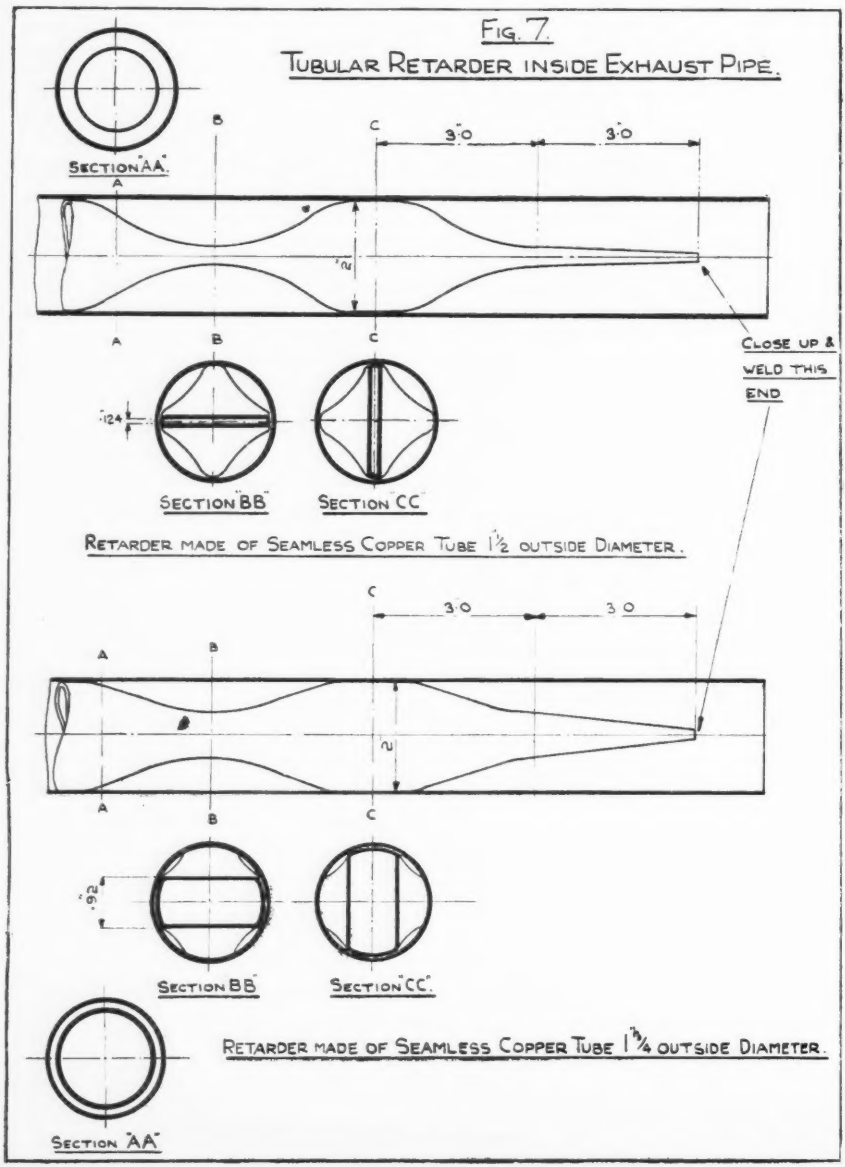
The recovery apparatus fitted to Rigid Airship No. 1, in 1910, consisted of some 400 feet of thin metal pipe led from the exhaust manifold aft along the keel and then forward again to the engine car where it was fitted with a water separator. The airship never flew as she was broken when being returned to her shed after a mooring experiment. A trial with this apparatus in the shed gave a water recovery of 52 per cent. of the fuel weight.

At Kingsnorth, in 1917, a honeycomb radiator of 1in. tubes, 10in. long, was arranged to take the exhaust gas of a 240 h.p. engine through the spaces between the tubes, air from the airscrew passing through the tubes themselves. The recovery of water was very satisfactory while the tubes were clean but decreased seriously after some ten hours' running. The radiator was opened to examine the distribution of deposit and it was found that on the hottest surfaces there was practically no deposit, then a dry powdery carbon, then slightly oily carbon, and in the area where water had been condensing, a slime of oil and water. A separator box with strands of hairy wool was used to catch the particles of moisture—a somewhat unusual separator, but perhaps the lightest.

The recovery apparatus used in America appears—so far as may be gathered from published accounts—to employ long lengths of thin aluminium tube exposed to the airflow. A very large cooling surface is provided so that cooling shall still be satisfactory after part of the surface has been rendered comparatively ineffective by fouling. The resistance caused by the apparatus is said to reduce the speed of the airship by three miles per hour. The figures given for percentage recovery make no mention of the atmospheric conditions or of the length of time for which the recovery was maintained. They are, therefore, little indication of the merit of the apparatus.

The foregoing is admittedly lacking in description of any actual successful apparatus, but that lack is unavoidable at the present stage.

A great deal of investigation of the factors controlling the general problem has been made, and certain systems which are often proposed have been investigated and put aside.



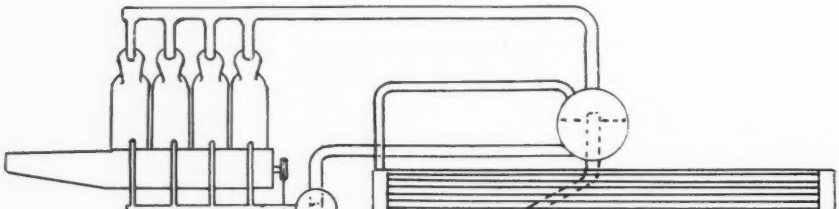
It is hoped, however, that the considerations here set down may be of assistance to some and that they may be constructively criticised now or at any future time.

Many people have contributed to the work described in this paper. Perhaps the greatest assistance was given by Mr. M. A. Giblett, Superintendent of the Airship Meteorology Division of the Meteorological Office, who supplied the large quantity of meteorological data referred to and drew attention to the Hertz diagram as a means of making from them calculations which by any other method would have been extremely laborious.

Discussion

Sir Sefton Brancker, in opening the discussion, said: I am extremely glad to be able to be present at this joint meeting. This is the first time I have heard of this idea of applying cooling by means of condensation of steam to aircraft; anything that is going to reduce the drag and the head resistance of aircraft will be very valuable in future progress toward improving efficiency and gaining in performance. One thing I am a little hazy about; why does the Author claim this reduction of drag? And I would like to hear where the radiators are to be installed on the aircraft and how it is intended to carry the excess heat to the passengers' cabin. That interests me personally because we are studying the problems of ventilation and heating of passengers' cabins at the present moment. I do not agree that the paper is premature. I think it has come just about at the right moment. It seems to me that this is a very fitting time because we have just had the demonstration of Senor de la Cierva's autogyro. One of the difficulties of that invention—or rather one of its weaknesses—is the difficulty of cooling the engine; aircraft cooling depends on high speed; with de la Cierva's machine it is proposed to fly very often at something like 10 to 15 miles an hour. At such speeds existing engines overheat and give trouble very quickly. The Author has given us a glimpse into the fascinating subject of the navigation of airships and from what he has said you will realise that this system of water recovery has revolutionised the methods of handling airships and much diminished the cost of operation. One thing may be of interest to mention. In Irak, during the hot weather, you meet a very violent inversion of temperature indeed. At night it is quite cool on the ground and you start off in the early morning on a flight thinking that you are going to be delightfully cool in the air; but the moment you get up to three or four hundred feet you plunge into burning air, which I should think must be 20 or 30°F. above the temperature on the ground; this heat continues up to 5,000 or 6,000 feet when you begin to get comfortably cool again. I fancy that these conditions will make it extremely hard to obtain efficient water recovery in airship operating in the hot weather. Before sitting down I should like to express my appreciation, as Chairman of the Royal Aeronautical Society, of this idea of joint meetings. We in the Royal Aeronautical Society touch the activities of many other bodies and various lines of scientific development; we do want to bring other people into our counsels and get them to help us in our various problems, particularly in connection with the internal combustion engine which, after all, is the life blood of aviation to-day. Therefore I thank your President and the Council of the Institution of Automobile Engineers for arranging this meeting to-night.

Mr. Manning: With regard to evaporative cooling, I should like to call attention to the early work on this subject by the well known French engineer Levavasseur. I refer to the original type of Antoinette aeroplane and engine, and as the system used there was somewhat different from those described to-night, I should like to show a diagram of the arrangement.



Antoinette Cooling System.

It will be noticed that in this system there are two water pumps, one being used to circulate the water round the engine, to and from the water tank; the other arranged to collect the condensed steam from the bottom of the radiator and return it to the tank. Unlike the systems tried by the Lecturer, the steam is introduced into the top of the radiator and withdrawn from the bottom. An automatic valve was also fitted in the tank, arranged to open at a small pressure either above or below atmospheric, the latter being necessary in view of the possibility of the collapse of the tank after use when cooling down.

This system as used on the Antoinette machine was certainly successful. The Antoinette engine was an eight-cylinder engine giving 50 h.p. running at 1,200 r.p.m. I think we are very much indebted to the Author for drawing our attention once more to this subject of evaporative cooling. Until recently the resistance of the radiator has varied inversely as the cooling required. I refer to the ordinary honeycomb type of radiator which has a number of shutters in front of it. In that type of radiator the resistance when the shutters are closed is about double that when the shutters are open. That to some extent has been modified on the later types, but I think there is no question that in the future the surface radiator will come in more and more. By that I mean that type of radiator which is attached to the surface of the plane. As far as information is available the resistance of that type of radiator appears to be very small. On the other hand, it suffers from the disadvantage of being a long way from the engine, and steam-cooling should help matters very much by reducing the weight of the connection—the pipes and contents—between the engine and the radiator. I agree with the Author that the weight of such a system should be less than ordinary water-cooling, and from the military point of view it is important that a bullet hole through the radiator would in all probability only mean a steam loss and not a water loss. Such a machine might be able to get home safely if fitted with a steam radiator, whereas it might come down in enemy country if fitted with a water radiator. The subject of water recovery on airships is not one with which I have anything to do, but I think the chief trouble in the recovery of water will be the rapid loss of efficiency of the condenser due to the deposition of oil. It does not require very much oil on the surface to reduce very considerably the transmission of heat. Although I am not at all well up in the subject, it has always been a matter of surprise to me that in an engine of this type, in which the oil supply is carefully regulated, you get lubricating oil coming out of the

exhaust in a normal state, and one finds it difficult to imagine that oil can pass through an engine and be subjected to the high temperature of the explosions and yet leave the engine in that state without being burned. One possibility may be the improvement of piston lubrication which will diminish the amount of oil that is lost in that way; unless that can be done I am afraid the Author is up against a serious difficulty.

Mr. J. D. NORTH: I have not come here to-night to be converted to a belief in the evaporative system for cooling engines. The Author converted me some considerable time ago; indeed, as soon as he told me that a modern engine had been satisfactorily cooled by boiling the water in the engine. I remember that he wrote me a letter about this point two or three years ago, and although I made certain criticisms at the time of the condensing system which he proposed (and I think he did not disagree with them), I particularly emphasised the fact that it was rather a matter which would have to come from the engine manufacturers; that if we could be provided with dry steam we should be able to condense it. However, I am rather inclined to think it is one of those problems concerning which we are likely to fall between two stools. Perhaps the engine manufacturer has waited for the aeroplane maker to solve the condensing problem, while the aeroplane maker has waited for the engine manufacturer to provide the steam, and I think we must be very grateful to the Author that he has caught the problem before it reached the ground. One of the special advantages of evaporative cooling is in relation to the surface of radiators. It gets over the great difficulty of the water space involved in wing radiators and also the very important difficulty that they are very fragile. I believe there is also reason to believe that with steam cooling the radiators might be made more flexible—of non-metallic material—because conduction plays a very small part. The back resistance of conduction is very small compared with the limitations of convection cooling. I do not know whether the Author can tell us, in connection with the Rushmore system, how that valve is arranged. It appears to be arranged to allow air to come into the system possibly for the same reason as has been shown in the Antoinette engine. One would have thought that it would have been advantageous to have the valve set to blow off at a certain pressure, because when the water is wholly condensed, as it would be when standing in the shed, you would tend to get less air in the system for starting up.

To turn to the second part of the paper, it does not seem to me that there will be quite the same ease in dealing with the surface radiator question for water condensation, particularly as the temperature differences are so very small that it may be necessary to go in for high conducting radiators just at the very particular time when to be able to use a radiator of fabric construction would be a most exceptional advantage. Mr. Manning has pointed out the effect of a small quantity of grease in radiators and that is a thing which has accounted for a great many anomalies in tests on radiator surfaces. Wind tunnel tests have been made on radiators and some considerable discrepancies have been found between these tests on machines in service, and in nearly all cases these have been due to grease getting inside the radiators. The Author made one statement in the second part of the paper which rather alarmed me. He suggested that we should all do our work on heuristic principles, that is to say, that we should start *ab ovo*. I think that is rather a dangerous method of going to work. It may be better from an educative point of view. I believe the modern theory of education is that it should proceed on heuristic principles, but I think in engineering developments we must always remember the advantage which the dwarf had by standing on the giant's shoulders, and I hope the Author's enthusiasm for the heuristic principle will not, in the future, rob me of the pleasure of standing on his shoulders. One point arising out of that is very attractive. It would be very attractive in informing foreign representatives that we are not permitted to show them certain work which is going on over here, but we

should be able at the same time to say that the grounds for this are not to avoid the disclosure of an official secret, but rather lest the visitors' mental faculties should be impaired. But this is by the way.

We must all thank Commander Cave, whose enthusiasm has kept this problem boiling for several years in a somewhat chilly atmosphere, and who has so kindly condensed for us in his paper to-night some of the distillation products which have resulted.

Mr. STILL: I think my presence here needs a little explanation. I am perhaps unknown to a number of you here, but the engine which bears my name is one which employs complete evaporative cooling, and the fact that I have spent the last 12 or 14 years in intensified work on that subject gives me, perhaps, some claim to offer a little information on the subject. My difficulty is not that of the Author, because I have plenty of facts. My difficulty is that a great number of them are not applicable to your work at all, because my work has been in connection with engines of 2,500 h.p., weighing 300lbs. per h.p. and running at 120 r.p.m. That is clearly absolutely outside your domain. The best that I have done in your direction is an engine of 360 h.p. per cylinder weighing 29lbs. per h.p., inclusive of boilers and condensers. I can frankly say that I did not expect to take part in any such discussion as this because I was unconvinced that any type of evaporative cooling could be got down to suit your needs on the question of weight. This paper, however, has opened my eyes to the fact that there are other advantages from your point of view which I had not appreciated. My difficulty is that the various factors involved in applying such a system to your service differ so very widely from my practice, that it is rather difficult to say where the ultimate outcome will be. There are, however, some points of interest in our research which are common to all engine manufacture. First, it has been said that there is little change in the operation of the engine *per se*, if you raise the temperature of the cooling system, but that is not our experience. Our experience is that an increase of temperature, due to the employment of evaporative cooling, creates a new engine condition, and the engine needs a considerable amount of modification in order to suit the new conditions produced. It was not until we realised that fact that we really got commercial results. One of the points I think you will probably find in petrol engines is that you will have to slightly lower your compression. The tendency to pre-ignition occurs at an earlier stage if you raise the temperature of the jacket water. On the other hand, there is a gain which you will undoubtedly have in mechanical efficiency. Our big engines, tested by the Marine Oil Engine Trials Committee, show mechanical efficiencies up to over 90 per cent. as against under 80 per cent. for Diesel engines. There is one point which seems to come out of the discussion also, and that is that if you are going in for an evaporative system why not make use of the steam you evaporate. In my case, at full power we get an addition of from 15 to 30 per cent. from the steam we evaporate. In our large engines of 2,500 h.p., the whole of the friction of the engines and the whole of the working of the auxiliaries and the work of the scavenging blowers is done by steam; as a consequence the brake power of the engine is equivalent to the combustion indicated power. That is a matter which I do not think is unworthy of consideration in a machine like that used on aircraft and where radius of action and weight carrying are both important factors. I can endorse Prof. Gibson's statement as to heat transmission. The temperature differences between water and metallic surfaces when cooled by boiling water fall very remarkably the instant the boiling stage is reached. We have made extensive tests in that direction at rates of heat flow running up to 100,000 B.Th.U. per hour per square foot and the difference between the water surface and the metallic surface is very small indeed. It is of the order of 10 to 15 deg. Fah.; actually, in our trials to-day, the inner wall of our cylinder—the surface exposed to the gases—registers about 50 deg. F. above the evaporating temperature of the water, and we work

on an evaporative temperature of about 360 to 380 deg., which is equivalent to 150lbs. steam pressure. I have found it perfectly easy to avoid steam pockets and there is no trouble in that direction with quite reasonable design. It is necessary, however, to be careful to maintain continuous circulation of the water. Circulation of this character very soon descends into what I would call "gusting" action in which you get an explosive circulation rather than a steady flow. It is very easy to do that, and there is then a tendency to frothing and bubbling and for the steam to run along the surface of the water and not for the water itself to move. That has been observed in a very interesting manner in glass tubes on fairly large scale experiments. The surface of the water is hardly moving at all. You will see some waves on the surface, but they do not indicate a circulation of water and it is necessary to prevent that kind of action. I think for this reason the Rushmore system of water circulation will be quite unsuitable for large powers. There is one great difficulty which I am afraid will be met with in cooling exhaust gases down to the point of condensation, and that is that these gases are nearly always very rich in acid and considerable corrosion of the tubes might be met with. In our case we were careful to avoid cooling our gases down below dew point and I think there would probably be considerable trouble if this is done. Of course, we do not use as high rates of transmission per square foot of surface as may be used in your case, but I have not found a thin skin of oil on the surface of our regenerators much of an impediment to heat transmission. We have a number of engines in regular commercial service on our system and the first marine set is just back from the fourth voyage to the East and has traversed nearly 100,000 miles of sea, so that we have gained some experience; my trouble to-night has been to sort out from that experience items which may be of service in your especial branch of engineering.

As this is a combined meeting of both Societies, I should point out that the Still engine has, to my mind, little scope in automobile service except in big tractors or for large powers. There are no Still engines made to-day below 100 h.p.

Mr. E. B. Wood: When I first saw the title of the paper I very much hoped that it referred to what I may describe as internal evaporative cooling upon which some experiments were carried out in 1913 by the late Prof. Bertram Hopkinson.* I think that has considerable possibilities, particularly in connection with the recovery of water from the exhaust, because the great defect for land use is the mineral salts always found in water, also the sulphur in gas, and probably no one would trouble to use distilled water. I think it is not safe to assume that because certain heated parts of an engine, such as sparking plugs and exhaust valves, do not now cause much mechanical failure they are not the root of other trouble. If you consider the possibility of the internal cooling of these parts it may be that you could increase your compression ratio and consequently improve your economy. It would appear that it should not be very difficult to recover the whole of this injection water, as the water produced by the combustion of the fuel is more than enough to saturate the exhaust gases at perhaps 20°C. above atmospheric temperature. Of course it does entail a certain amount of complication in that there would have to be a pump arrangement for working the spray, but it would seem that you would have a limited air cooling of the head and with the use of the internal cooling you would not have to use a great deal of water. The only other point is that I should like to explain my idea of the reason why you can get a steam lock in the cylinder where you are not likely to get an air lock. If one imagines some sort of bottle neck construction, the air in it is only a certain small amount and you can release this through a comparatively small hole, but the steam is continuously being formed and would tend to force the water away from the bottle neck. That seems to me

* Proc. Inst. Mech. E., 1913. Part III., p. 679.

a possible explanation, though of course this is more likely to happen in a motor car cylinder where you sometimes get fins in the jacket casting caused by the metal running between the joints of the cores, which you would not get in an aircraft engine jacket which is usually welded.

Engineer Captain L. M. HOBBS, R.N.: The transference of heat through metals is a subject of the greatest importance to marine engineers as well as to automobile and aeronautical engineers, and it may therefore be of interest to mention some of the rates of heat flow that we have to deal with in connection with marine oil-fired boilers where the rates of forcing are probably the maximum reached at the present time. The Author refers to the Lion engine, which has a rate of heat transmission of 850 B.Th.U. per sq. ft./minute. The rate of heat transmission that we get with an oil-fired boiler is often such that it evaporates 100lbs. of water per square foot of heating surface per hour, which gives a rate of heat flow of the order of 1,880 B.Th.U. per sq. ft./minute. The maximum rate of flow is estimated to be of the order of double that, *i.e.*, 3,660 B.Th.U. per sq. ft./minute. This is a very high rate and occurs where you have water on one side at about 400°F. and gases at a temperature of 2,750° on the other side of the tube. In the case of superheater tubes, where we have steam only on one side and hot gases of the order of 1,450°F. on the other side and a final superheat temperature of 190° above the saturated steam temperature, the rate of flow averages about 300 B.Th.U. per sq. ft./minute, but the actual rate is approaching double that for the tubes nearest to the fire. Therefore these rates of heat flow are considerably above some of those mentioned in the paper. We have not any difficulty as long as the metal is kept scrupulously clean on the water or the steam side, but that is important because the slightest trace of scale or grease may result in overheating when using these very high rates. From this we may deduce, with regard to aero engines, the necessity for using the purest water where high rates of heat flow are to be used, so that there shall be no scale deposited on the jacketed surfaces, and certainly there should be no oil in the water as it is very liable to cause overheating due to the non-conducting film it forms. Another very important factor we have found in using these very high rates of heat transmission is the velocity of water or steam through the tubes. This should be as high as possible, and this suggests that a very rapid motion of the steam formed in the jackets should take place. A third point I want to make is that in order to get these high rates of heat flow, it is necessary that the surfaces should be as smooth as possible. If there is anything in the way of roughness, such as a powdery deposit, this will catch little bubbles of steam and prevent them flowing, and this stationary steam film will tend to cause overheating. Another point that interests me very much is the Author's triangular form of radiator for cooling the steam. If this be inverted it is really very similar to the type of condenser very largely used for marine purposes, and this is rather interesting as showing how research in one branch is helpful in another. It has been found that that type of condenser has enabled higher efficiencies to be obtained for less weight. It has been found advisable, however, to open out the spaces between the tubes at the top, where the steam comes in, in order to get the steam rapidly condensed, and experiments have shown that the condensation does not take place uniformly, but that condensation occurs more or less in gulps. Therefore, it is necessary to have as much surface as possible in contact with the steam immediately it comes in. Hence, in a condensing radiator it might also be advisable to open out the honeycomb spacing at the bottom in preference to a uniform spacing throughout. I should be interested to hear what is the highest permissible temperature of cylinder walls of an aero engine to maintain lubrication under long continuous running conditions. Prof. Gibson's curves indicate that the average temperature of an engine will be less when evaporative cooling is employed than when water is used for any temperature above 60°C., but below this temperature the curves are very

rapidly descending and indicate the engine will be more effectively cooled when water is used, and it would be interesting to know whether the temperatures corresponding to evaporative cooling approach the limit necessary for proper lubrication. What is the margin? This is particularly interesting with reference to the suggestion that abnormally hot air temperatures may be experienced sometimes when flying.

Mr. A. E. PARNACOTT: I have had experience of steam and internal combustion engines; perhaps I can ask some questions of the Author and also give information which may be useful. I suggest, as a way out of the difficulty of bubbles forming on the cylinder walls of the engine, and also bearing in mind that steam should not be allowed to bubble through considerable depths of water because that is conducive to priming, that the water pumped into the cylinder jackets should fall over a weir and back again, and that a heat operated pressure valve be fitted to the cylinders to maintain the cylinder water at the boiling point or at whatever temperature you require the water to remain at. If you require it to remain at about 212° or 220°, you cause the valve to blow off at those temperatures corresponding to pressures up to 18lbs. per square inch at sea-level. That will get over the difficulty of the explosive film of water. I should like to suggest to those who are interested that a very impressive experiment can be carried out in a very simple manner in this connection. If you take a blind tube, *i.e.*, stopped up at one end, and put the stopped end in the flame of a Bunsen burner with the other end in cold water, that tube will chatter and fly into the air showing that violent pulsations of water occur and that the effects are really dangerous. This illustrates very clearly the point made by Mr. Still.

With reference to the cooling of the steam, I think it would be advantageous to bear in mind that the condensation of the steam is accelerated by contact with water. If the film of water on the cooling surface be thick, *i.e.*, if the cooling water on the radiator is too thick, you will find that re-evaporation may apparently take place, and I suggest that the radiator be formed so that soon after the steam has condensed into water it should be conducted away to the container. In steam practice there is a system coming very largely into use known as the contraflow system and it is conducive to efficiency. It means that the hotter mediums should meet and the cooler mediums should meet; in that way one gets a higher efficiency, though of course you may contend that you have plenty of cold air; such an arrangement is weight saving. The flattened tube which the Author has shown is, I think, a tube which was patented by Rowe many years ago for breaking up the core of steam or gases passing through the cooling passages. Perhaps the Author did not know that. I should like to know if any steps have been taken to remove oil and soot from the exhaust before it enters the radiator.

To conclude, I would like to suggest that developments having taken place in the direction not of an engagement between, but a marriage of, the steam engine and the internal combustion engine, might we not very carefully consider the construction of an entirely new type of engine? I am referring to the construction of a steam engine, but I do not mean a water-steam-water engine. For aircraft, and particularly for airship purposes, some consideration ought to be given to an engine in which water would in the first place be converted into steam and the steam superheated and allowed to expand in the cylinders and again heated up, but not allowed to condense into water. There are no patents that I know of in that direction, so I am free to make this suggestion.

Mr. W. E. GRAY: I should like to ask the Author if there would be any objection to making the section of the triangular radiator triangular in the other direction.

Dr. BARR: There are a few small points I should like to mention. One is that the steam-filled radiator on aircraft will be considerably affected by increasing

the height, not only because the temperature of the steam falls, thus reducing the efficiency of the radiator per unit area, but also because the volume occupied by a given mass of steam is increased so that a larger radiator volume is required than suffices at ground level if steam is not to be lost. Turning to the second part of the paper, I notice that the weight of air per pound of fuel is taken at 38lbs. for maximum economy. In view of the conclusions reached later in the paper it may be necessary to strike a balance between economy of oil and of gas. The curves showing the effect of height on recovery indicate that the temperature variations constitute the most important factor in the effect of altitude. These diagrams are important as pointing to the need for a new type of navigational skill which may be required in the future to strike the course and altitude most consistent with economy both of fuel and of gas. The comparison of recoveries obtainable is based on the assumption of an apparatus capable of cooling the exhaust to 10°C. above the atmospheric temperature. That is probably rather unduly hard on unfavourable atmospheric conditions, because if there is only a little water being recovered the cooling will be very much more efficient, owing to the fact that the latent heat of condensation of the missing water does not have to be dissipated. In view of the importance of this latent heat in the later stages of cooling, I suggested some years ago* that the condensation should be assisted by water cooling. The Author points out that the employment of the usual types of radiator to cool the gas and water would involve enormous areas of contact and hence enormous weights. I would suggest, however, that the requisite area of contact between water and exhaust gas might be secured by spraying the water into the exhaust pipe near the separator end, as is done in many air-conditioning systems; by this means the heat may be transferred from the gas to the water. The more difficult problem of getting rid of the heat from the water still remains; providing considerations of weight do not debar it, the existing surface of the ship might suffice if the water were sprayed inside the gas bags and again collected. It sounds a little revolutionary and there would probably be some increase in the volume of gas and in the sensitiveness of the lift to temperature changes. These disadvantages would be outweighed by the possibility of varying the relative temperatures and lifts of different parts of the gas system. It seems probable, from a superficial examination of the procedure, that the gas, and hence the collected water, need have a temperature only very little above that of the external air. When the air is warm and dry and the possible water recovery very small for the case assumed by the Author (when the temperature of the exhaust is lowered to 10° above that of the air), a material improvement might be effected by the following device. Suppose the water, now only slightly warmer than the air, is again sprayed, this time through the inlet air. The water would be cooled, possibly nearly to the wet-bulb temperature, so that it would be conceivable that the exhaust might be cooled by this means even below the temperature of the ambient air. As to the advantages accruing to the operation of the engine from the use of cool moist air, I need not remind you.

Professor A. H. GIBSON, D.Sc.: I have read Commander Cave-Browne-Cave's paper with much interest and appreciation.

In connection with the question of evaporative cooling, with special reference to the effect on performance of an increase in the temperature of the cooling fluid, some figures obtained in tests on an aero engine cylinder under my supervision may be of interest.

In these tests, aniline was used as the cooling medium, the mean temperature in three successive tests being respectively 52°C., 120°C. and 157°C. The following are the essential results:—

* Reports and Memoranda of Advisory Committee for Aeronautics, No. 234. 1915.

Temp. of cooling fluid.	Relative fuel consumption per b.h.p.	Relative b.h.p. at full throttle.
52°C.	1.00	1.00
120°C.	.938	.985
157°C.	.952	.945

The figures indicate that any such increase in temperature as is likely to accompany the method of evaporative cooling is not in itself likely to influence unfavourably the performance of the engine.

There is one point, however, about which I am not very sure. Experiment shows that the deposition of a film of scale on the water surfaces of a cylinder has a serious effect on the cooling, and in the case of a hard or impure water being used, it is possible that deposition will be more marked and its effect more serious when evaporative cooling is used. This is, I think, a point which should not be lost sight of.

In connection with the cooling of exhaust gases, I would suggest the use of an ordinary Row tube instead of the plain tube with the baffle, shown in Fig. 7, as being lighter and probably as efficient. From experience with exhaust gas coolers, I should anticipate much trouble from corrosion especially in those parts of the cooler exposed to the condensed steam.

Brig.-General J. G. WEIR: Commander Cave-Browne-Cave's paper is of deep interest to all engineers dealing with internal combustion engines. The heat rejected by the internal combustion engine in jacket and exhaust gases is a continual challenge. As matters stand, it is merely an embarrassment and involves heavy and troublesome apparatus to get rid of it. As matters should be, it is a valuable by-product capable of increasing vitally the economic value of the engine. The most obvious way of utilising this heat is to raise steam by it, and Commander Cave-Browne-Cave indicates that in raising and condensing steam we have incurred no further disadvantages in our apparatus for dissipating the heat, but rather an improvement in efficiency and lightness.

The next step must obviously be to put the jackets under pressure and insert a turbine in the circuit to the condenser. The supercharging blower only awaits the advent of this turbine to become an integral unit of every internal combustion engine. The condenser offers a novel problem in the design of heat transfer apparatus. Sufficient data already exists to enable the steam side to be fairly accurately proportioned, and if the design is so made as to maintain a rapid steam flow over the cooling surface, a transmission rate of 1,000 B.T.U.s per hour per sq. ft. per 1°F. temperature difference should be possible. On the cooling air side the data for the optimum air path are not so well known.

On the basis of experiments I have carried out it would appear that there is a definite surface/section ratio of path which is most efficient in respect to amount of cooling for a given head resistance. To conserve this requirement and to maintain uniform steam velocity on the steam side requires a form of radiator having large diameter long tubes at the steam inlet tapering down to small diameter short tubes at the air vent.

With regard to the problem of exhaust water recovery, Commander Cave-Browne-Cave has most clearly portrayed its importance and equally clearly the difficulties in the way of a solution. It appears to me to be a matter in which the chemist must give his assistance. The most important constituent of the exhaust is CO_2. Less than one-third of the escaping CO_2 need be retained to maintain weight equilibrium. Would this not be more easily achieved than the trapping of an equivalent amount of water?

Major P. L. TEE : Having been debarred, due to a prior engagement, from being present at Wing Commander T. R. Cave-Browne-Cave's lecture, I should

like in the first place to add my praise to that which I am certain the Author has already very rightly received on account of his masterly exposition of two, by no means, simple developments in connection with aircraft engines. I would also congratulate the Air Ministry for allowing a serving officer to read a paper dealing with matters which, while at present in a distinctly metamorphic state, are likely, as a result of the discussion occasioned by the paper, to become more definite and precise.

Dealing in the first place with evaporative cooling, the following are the advantages which it seems to offer with existing engines:—

(1) A reduction in the total weight of cooling water carried, for with evaporative cooling the radiator is initially dry.

(2) A more rapid heating up of the engine when starting up, due to the decreased weight of water.

(3) An automatic control of the cylinder jacket maximum temperature depending merely on the atmospheric pressure at the height at which the machine is flying.

(4) A slight reduction in the fuel dilution of the crankcase oil due to the higher cylinder wall temperature.

(5) The possibility of steam heating in the aircraft.

Against the first of these advantages (even when no secondary use is made of the steam) there has to be offset the additional weight of a certain amount of extra pipe work and also that of the water steam separator, consequently I should like the Author of the paper to give figures as to what nett reduction in weight he can promise with any specified engine. Further, I would invite his opinion as to whether, if the water jackets of an engine were especially designed for evaporative cooling, an increased water weight reduction could be expected.

In the paper it is pointed out that if it is desirable, the boiling point of the water can be raised by the use of mineral salts. While this is perfectly true, such salts have a very marked tendency to lead to much more rapid corrosion, however, since the raising of the boiling point can be obtained by the use of glycerine without the above disadvantage, one would like to know what reduction in radiator resistance Wing Commander Cave-Browne-Cave would anticipate if the boiling point of his liquid was raised to 125°C.

Dealing with steam heating, this, while appearing very attractive for aeroplanes, seems in airships to present somewhat formidable difficulties, for the spaces to be heated are often a considerable distance from the nearest engine, thus necessitating considerable lengths of lagged steam and return water pipes, while due to the pitching of the airship one anticipates water surging troubles in the return pipe, a matter which would seem to require careful consideration.

In concluding one's remarks on this subject, it is but right to say that as far as evaporative cooling has now been carried, due in the main to Wing Commander Cave-Browne-Cave's exertions, it presents many attractive possibilities which it is to be anticipated further research will augment rather than diminish.

Water Recovery.

Since during flight an airship becomes increasingly lighter, due to the weight of fuel consumed in the engines, in order to maintain control of the vessel, from time to time it becomes necessary to valve hydrogen or other buoyancy producing gas.

If the airship is inflated with hydrogen, to reduce this otherwise essential waste of gas two courses are possible:—

(1) The burning of hydrogen in the engines approximately equal in buoyancy to the weight of liquid fuel consumed, a procedure which

promises a very considerable reduction in the actual weight of liquid fuel which will be consumed in a definite length of flight.

(2) The recovery of water from the exhaust gases of the engines equal in weight to the fuel consumed.

The disadvantage of the first system is the expense of the hydrogen consumed, for if this costs 7/- per thousand cubic feet and petrol 1/6 per gallon, the heat energy of the hydrogen is 2.4 times that contained in the petrol; however, this drawback, in the case of commercial airships, will be entirely outweighed by the improved paying load which can be carried as a result of reduced liquid fuel consumption.

Since the combustion of hexane can be represented by the following equation :—

$$\underset{2C_6H_{14}}{\text{Hexane}} + 19\,\underset{(O_2+4N_2)}{\text{Air}} = \underset{12CO_2}{\underset{\text{Dioxide}}{\text{Carbon}}} + \underset{14H_2O}{\text{Water}} + \underset{76N_2}{\text{Nitrogen}}$$

100 parts of hexane by weight consumed in the engine produces 146 parts of water, but since at 100°C. the volume of water in the exhaust, assuming the impossible condition of its all being in the liquid state, is .0096 per cent., it is at once apparent that the actual collection of the water, quite apart from the cooling of the exhaust, presents a formidable problem.

Since the exhaust gas on leaving the cooling system must of necessity be fully saturated with water vapour, this physical requirement has, as is so clearly pointed out in the paper, an enormous influence on the amount of water which is even theoretically recoverable. If the engine is operating under the conditions given in the equation, the induction air is absolutely dry (a purely theoretical condition), and the final temperature of the exhaust gases is 125°F., no water whatever is recoverable. As can be appreciated from the paper, under many conditions of tropical flying which will be met with in practice, it will be impossible for many hours on end to recover, using Diesel engines, an amount of water even closely approaching the weight of liquid fuel consumed; consequently, taking this fact into consideration, in conjunction with the increase in weight and head resistance which the recovery apparatus necessitates, the system which Wing Commander Cave-Browne-Cave has so ably analysed does not at the present stage of its development compare favourably with the alternative which is referred to in this note. However, great as are the difficulties to be surmounted, one hopes that the Author, as a result of further research, will be able to make substantial improvements, possibly by incorporating a desiccating agent in the recovery system.

Mr. A. G. Herreshoff (Superintendent of Rushmore Laboratory): It is indeed refreshing to find such a detailed and able discussion on the subject of cylinder temperature control—a subject long neglected. Few seem to realise that the object of a so-called "cooling system" is not to cool the cylinders but to maintain them at some desired temperature.

On considering the removal of heat from a heated surface by the formation of steam it is at once apparent that, as steam is generated only from the film of water immediately adjacent to the surface, all that is necessary to effectively "cool" that surface is to maintain the film or to have the surface wet. The seething mass of bubbles above a violently boiling liquid will supply the small amount of liquid necessary. Indeed, this condition already exists in the so-called water-cooled engines, for the ejection upwards of half the water in the jacket can only be produced by steam generated on the hotter surfaces, so keeping the body of the water away from such surfaces.

Conditions in the cylinder jacket adjacent to the hotter spots are almost exactly similar with hot or cold feed-water, and the agitation, when viewed

through a glass jacket wall, is many times more active than can be produced by pump circulation.

The Rushmore system was at first designed to produce an active pump circulation, which has been found to be unnecessary and undesirable on account of the increased resistance to the flow of steam.

A small positive pump to return the condensate with 100 to 150 per cent. excess is used. The only requirement is that the pump shall be below the lower radiator tank and gears and shafts be made of rust resisting material or of hardened stainless steel.

The saving in weight and in power to operate the pump is considerable when expressed in percentage of pump power, but is insignificant when compared with the total engine output. The saving in fuel with the Rushmore system is due almost wholly to the reduced piston friction.

It is well known that there is a reduction in piston friction as the temperature of the walls is increased and a reduction of 50 per cent. has been shown from increasing the jacket temperature from 122° to 212°F. As the piston friction is 50 to 60 per cent. of the total mechanical loss the above temperature increase will effect a saving of 25 per cent. of the mechanical loss which, at "average" or quarter load, is fully 60 per cent. of the indicated horse-power, so that the expected increased efficiency at quarter load would be 15 per cent. Careful tests have shown a decrease in fuel consumption of from 15 to 20 per cent.

It should be remembered that it is the temperature of the inlet water directed against the cylinder walls that controls the piston friction loss, not the temperature of the discharge water which, in a thermo-syphon or thermostat controlled system, may be 100°F. hotter.

In road vehicles operating in a hot climate the increased temperature of the steam condensing radiator is of considerable importance and may amount to fully 30 per cent. increase in cooling capacity. The increased efficiency will, of course, decrease as the water cooling radiator operates with a smaller temperature drop and as the air temperature becomes lower.

In production, the sectional capped and vented radiator will be found exceedingly simple and inexpensive, as the caps are made an integral part of the core construction. The action of such a radiator is nearly perfect, for the pressure set up by the passage of steam through the vent is sufficient to direct any more steam through the unfilled sections.

With the use of steam heating it is desirable to have a back pressure valve on the main steam outlet from the jacket so that there will be a definite flow of steam through the heaters, thus blowing any accumulated air or water to the main radiator. In aircraft such a valve can be made adjustable so that a constant pressure and temperature can be maintained in the cylinder jacket, irrespective of altitude.

With this system the heaters simply form an auxiliary flow path from the engine jacket to the main radiator. The piping may be of very small size and run wherever convenient, without the least regard to air venting or drainage.

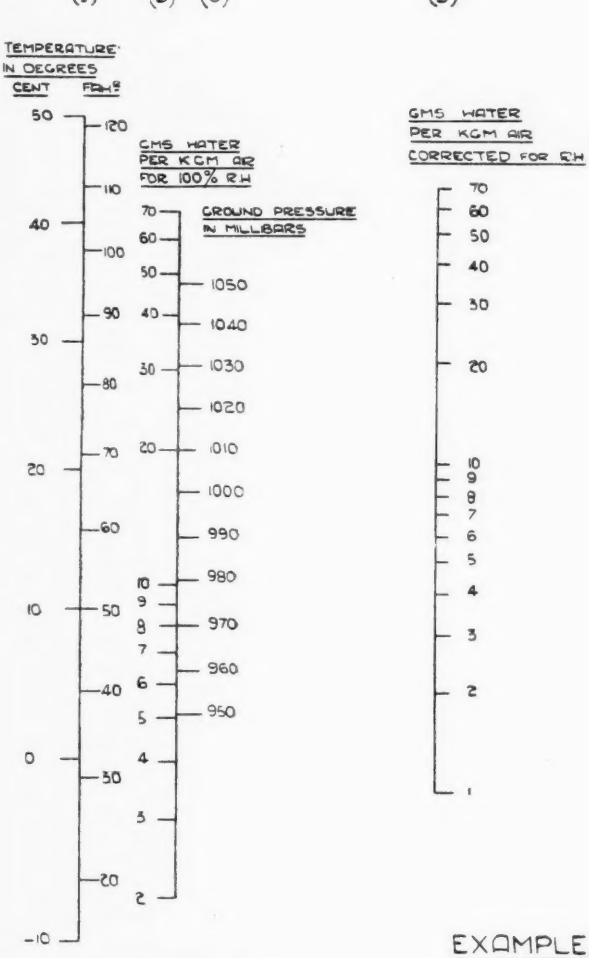
Tests have shown that, on an automobile, the steam from the cylinder jacket with the engine idling is fully 15 per cent. of the amount at full load, or vastly more heat than can be used or required for heating the passenger space.

Mr. F. L. LE BROCQ: In connection with the problem of water condensation from exhaust gases of aero engines, I submit herewith an alternative to the Hertz diagram described by Wing Commander Cave-Browne-Cave.

I enclose a tracing of the diagram on a reduced scale and furnished only with the major graduations. This consists of a nomogram and possesses the following advantages over the Hertz diagram:—

CHART FOR OBTAINING

AIR UNDER VARIOUS COND



EXAMPLE:-

TEMPERATURE	=	17·2°C (63°F)
PRESSURE	=	800 MBS.
GROUND PRESSURE	=	1000 MBS.
RELATIVE HUMIDITY	=	31%
TO FIND MOISTURE CONTENT.		ALIGN 17·2°C (63°F) ON (1)
		ALIGN 15·3 GMS ON (3)
TO FIND HEIGHT.		ALIGN 800 MBS ON (2)

OBTAINING MOISTURE CONTENT OF

VARIOUS CONDITIONS.

(7)

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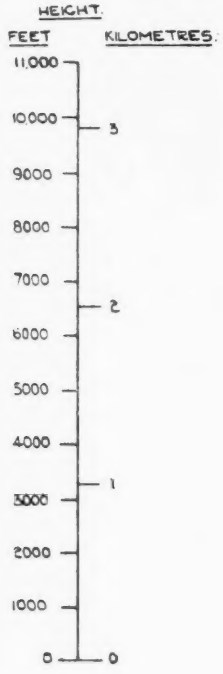


AMPLE:-

2°C (63° F)

0 MBS.

00 MBS.

%

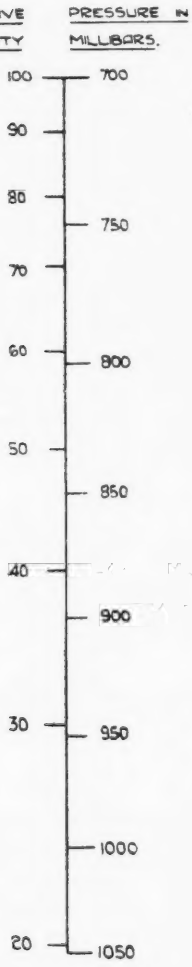
IGN 17·2° C (63° F) ON (1) WITH 800 MBS ON (2) AND OBTA

IGN 15·3 GMS ON (3) WITH 31% ON (4) AND OBTAI

IGN 800 MBS ON (2) WITH 1000 MBS ON (6) AND

NT OF

(4) (2)



AND OBTAIN 15.3 GMS ON (3).
ND OBTAIN AS RESULT 4.7 GMS ON (5).
6) AND OBTAIN 1.83 KMS (6000 FT.) ON (7).

(*a*) It gives the moisture content of the air for any relative humidity.

(*b*) When sub-divided it is more accurate than the Hertz diagram. The latter can only be sub-divided to a limited extent owing to over-crowding of the lines.

(*c*) Readings of temperatures in degrees centigrade or Fahrenheit or heights in feet or kilometres can be made with equal facility.

(*d*) The diagram may be extended to deal with higher temperatures without loss of accuracy.

Using the Hertz diagram the assumption is made that at 60°C. say, the moisture content of the air for 50 per cent. saturation is 50 per cent. of the moisture content of saturated air at the same temperature and pressure. Although at temperatures below 40°C. this error is negligible, at higher temperatures the distinction becomes important.

REPLY TO THE DISCUSSION.

This reply includes that made verbally at the meeting and answers the written contributions.

In reply to Sir Sefton Brancker, the reduction of drag is small if a honeycomb radiator is used. Steam is such a light means of conveying the waste heat that by its use the actual surfaces of the aircraft can be used for heat dissipation, thereby avoiding any other form of radiator and its consequent drag. It is also because steam is a light means of conveying heat to the passenger cabin that a generous supply of warmth can be provided for very little weight. The problem of engine cooling in an autogyro is difficult, because of the low forward speed which may exist, although the engine is developing considerable power. All cooling surface must therefore be in the slipstream of the airscrew and there a steam radiator would have no special advantage. It may be possible, however, to introduce steam into the surfaces of the autogyro itself, an arrangement which would be very difficult with any other system of cooling.

I am grateful to Mr. Manning for drawing attention to the Antoinette system. The radiator would not, I think, have been satisfactory under freezing conditions. Water recovery would be far easier if the exhaust were perfectly clean, unburnt lubricating oil being the most difficult deposit to deal with. The use of a certain proportion of hydrogen with the fuel will probably greatly reduce the amount of unburnt oil.

Mr. North refers to the relief valve used in the Rushmore system. This valve is, I understand, set to open at a slight positive or negative pressure. The ordinary honeycomb construction would probably collapse under small internal pressure, particularly if hexagonal tubes are used, but would withstand considerable internal vacuum. If no air were admitted to the system, the temperature would vary considerably with variations of power, and it is unlikely that the radiator could be strong enough or tight enough to stand for long under a very high vacuum when not in use.

I agree with Mr. North that the heuristic principle must be applied with nice discrimination whether to education, research or foreign representatives. If he had realised to whom I was applying it, I see he would have agreed.

Mr. Still's remarks on the change in the operation of the engine apply, I think, to cylinders in which the water jacket is evaporated under a pressure of 150lb./in.^{2}, and therefore at a temperature of 360°F. In the system contemplated for aircraft engines the jacket is at atmospheric pressure and the cylinder will therefore work under conditions identical with those of a water-cooled cylinder,

except that, as described in the paper, the temperature of the cylinder barrel is slightly hotter—with consequent gain in mechanical efficiency—while the temperature of the hottest parts of the cylinder head is actually reduced.

Mr. Still's remarks about gusty action in the water spaces are very interesting. It appears that the conditions in his cylinder jackets resemble those in a tank boiler rather than a water tube boiler, in which, at high rates of evaporation, the fluid passing through the tubes is a foam of steam and water. The conditions in the aero engine cylinder are much more similar to the latter. Corrosion in the exhaust gas cooling apparatus is recognised as a difficulty which can, it is hoped, be largely avoided by the use of suitable materials and by using fuel of low sulphur content.

I am grateful to Mr. Wood for describing a pocket which, although easy to free of air, might give trouble with steam. I agree with him and realise that such a pocket may often exist in a cast cylinder head. His proposal to remove heat by injecting water into the cylinder would be impracticable for aircraft, except in conjunction with water recovery. Even then it suffers from the defect referred to in my reply to Dr. Barr.

The figures which Engineer Captain Hobbs gives for the rate of heat flow are particularly interesting, because the contents of the boiler tubes in which this very high rate of evaporation is produced must be a foam consisting largely of steam. It is interesting to see how greatly the permissible rate of heat transfer decreases when the steam is superheated, and there is no evaporation taking place to facilitate the flow of heat normal to the surface. His remarks on the importance of having a smooth surface are a valuable warning, but such a surface will be difficult to achieve in an aero engine cylinder jacket, particularly in those parts which are cast and cannot be machined. In connection with the steam condensing radiator, it is understood that the final part of a marine condenser is arranged with decreasing area of flow converging to the air pump suction at the top. This agrees with the arrangement most suitable for aircraft where provision against freezing must be made. There is not any very satisfactory data as to the maximum safe surface temperature in the working part of the cylinder; 250°C. has been measured at the top of the working surface of an air-cooled cylinder, but it is not certain that this is the highest permissible. Mr. Still quotes 360°F. (182°C.) as a jacket temperature. This would correspond perhaps to 200°C. at the working surface.

Mr. Gray advocates making the radiator triangular in side view. This would, I think, be quite satisfactory except, perhaps, for difficulties of construction.

Dr. Barr advocates the removal of heat from exhaust gas by first transferring the heat to water. This water must be at the temperature to which the gas is cooled, say, 10°C. above the surrounding air temperature. To transfer the whole of this heat with a temperature drop of only 10°C. appears to involve unnecessarily large areas, and these areas must be capable of containing water instead of gas, and therefore comparatively heavy. The discharge of water into the hydrogen gas spaces of the ship would release in them a large weight of water vapour which could not be removed when desired and must therefore be regarded almost as part of the permanent weight of the ship. In addition to this weight of vapour a considerable weight of liquid water would be held on the surface of the fabric.

Professor Gibson gives very interesting new figures on the effect of jacket temperature. He suggests that the Rowe tube might be as effective as the combination of such a tube with an external tube as I describe. The advantage of the latter combination is that it can readily be thoroughly cleaned by withdrawing

the internal tube, whereas it is very difficult to clean the interior of a tube in which the flats are sufficiently pronounced to break up the core. Cleaning is very important, as any deposit so greatly reduces heat transfer. The baffle itself takes a considerable quantity of heat from the gas and transmits it to the tube at the areas of contact, thus increasing considerably the heating surface available in a given space. The formation of scale may give difficulty, but I doubt whether this will be more serious than in present water-cooled systems in which I am certain that much of the water is evaporated, although it may be recondensed before it leaves the engine.

The figure which General Weir gives for the condensation of steam per unit area of cooling surface appears difficult to apply to an air-cooled radiator in which the temperature of the surface will approximate much more closely to the temperature of the steam than to that of the air. To generate steam at considerable pressure would involve some change in the construction of most present aero engines. It was hoped that if a radiator of the same general type as that described in the lecture could be adapted to use a good vacuum, there might be sufficient heat energy available without modification of the engine itself.

The contents of the steam space of a radiator condenser are presumably at a fairly uniform temperature, that of saturated steam at the particular pressure. It was thought, therefore, that the same factors which govern the optimum length/diameter ratio of radiator tubes suitable for various wind speeds, would also apply to a radiator condenser. General Weir's reference to the work he has carried out is therefore of considerable interest.

The recovery of fuel weight in the form of CO_2 is attractive and in many respects simpler than the recovery of water. The weight of apparatus involved in the processes which so far have been suggested to us, appears quite prohibitive.

Major Teed asks for directly comparable weights of an evaporative and a water cooling system in the same aircraft. None are available at present, but it appears unlikely that a separator will be necessary in a system with pipes so short as will usually be possible in an aeroplane. The return pipe from the radiator will be small by reason of the small volume of condensed water. The other pipes and the radiator tank will contain steam. A considerable saving of weight, therefore, may be expected.

The cooling effect of a radiator is proportional to the temperature difference between the external air and the radiator surface. The addition of glycerine to the cooling liquid is likely to cause foaming and priming, but the use of a suitable material in the water to raise its boiling point is recognised as of considerable value, particularly at great altitude where water would boil at, say, 70°C.

The necessity of considerable lengths of piping to convey waste heat to the passenger space by steam is admitted, but it is doubtful whether there is any lighter means.

In estimating the economic merit of water recovery the cost of hydrogen at the refilling base should be used, and for this 7/- per 1,000 cu. ft. appears too low. It is unlikely that fuel costing 1/6 per gallon will be used in any commercial airship. Gas at 15/- per 1,000 cu. ft. and fuel at 6d. per gallon are perhaps more representative figures. The cost of a given quantity of heat energy in hydrogen and oil, respectively, is then about in the ratio of 17 : 1.

The cases calculated in the paper from representative meteorological data appear a better indication of the chances of water recovery than does Major Teed's hypothetical case. A combination of water recovery and hydrogen burning appears the proper provision. Until the handicaps involved in water recovery have been determined and the cost of hydrogen and the freight rates are known, no useful estimate of the economic value of the system can be made.

I am particularly grateful to Mr. Herreshaft for sending his remarks from the Rushmore Laboratory, in the United States, where so much experimentation on evaporative cooling has been done.

Mr. Le Brocq has proposed the arrangement of a nomogram which will possibly be easier to use than the modified Hertz diagram. When we have determined in exactly what form the data will be received, we will construct a nomogram as Mr. Le Brocq suggests and will then be in a better position to judge its relative accuracy and convenience.

CORRESPONDENCE

"Gweedore,"
7, Castle View Road,
Strood, Kent,
10th December, 1925.

Dear Sir,—I have just read in the current number of the Journal of the R.Ae.S. the paper on "Air Surveys in Burma."

I wish to take exception to the publication of certain details at the beginning of the paper. The heading is "Air Surveys in Burma, by Major C. H. Cochrane-Patrick, D.S.O., M.C. (of the Aircraft Operating Company)".

At the end of the first paragraph he states:—

> "Mr. Watson visited England later in that year and carried his negotiations during the ensuing year so far, that I remember when we returned from the survey of the Orinoco Delta and demonstration in British Guiana, at the end of 1921, that we expected to be on our way to Burma in the next few months."

As is well known in aeronautical circles, the Orinoco Survey was carried out by the Aircraft Operating Company and is, I understand, the *only* survey of any extent which has been done by them.

This would obviously lead the reader to the conclusion that the Burma Survey was carried out by the Aircraft Operating Company.

As a matter of fact this Company had nothing whatever to do with the Burma Survey, as the whole of the preliminary negotiations were undertaken by my brother, R. C. Kemp, and it was he who contracted to do the work, prepared the whole scheme, prepared the lay-out of the floats for the machines, had them built in this country and shipped to Rangoon, where he fitted the machines up as survey seaplanes. (They were, I believe, the first D.H. 9's to be converted to seaplanes.) It was he who carried out the whole survey, and he also did a considerable amount of the actual flying himself.

He has since formed a company, called the Air Survey Company, Limited, and he has carried out a further survey of the Mergui Archipelago for the Government of Burma, and a large survey of the oil fields in Sarawak for the Anglo-Asiatic Oil Company, and has just received a contract to survey a further 1,750 sq. miles of Sarawak from the Rajah of that country.

As regards Major Cochrane-Patrick, he was merely employed by R. C. Kemp as his pilot, I myself having interviewed him on my brother's behalf in December, 1923, and instructed him to proceed to Rangoon, where he was to report to my brother and carry out his instructions, which he did.

I would not trouble you with these details, but I think it is distinctly unfair, to say the least of it, for the Aircraft Operating Company to, indirectly perhaps, cause the impression to be created in aeronautical circles through the publication of this letter in such an influential journal as yours, that they were responsible for the success of this, the largest aerial survey conducted by private enterprise, when in fact they had nothing whatever to do with it.

My brother would have taken the matter up himself, but being in charge of operations out East, he is unable to do so.

I trust that on receipt of this communication you will cause a statement correcting this false impression to be published in your next issue.

Yours faithfully,

W. P. KEMP.

J. Laurence Pritchard, Esq., F.R.Ae.S.,
The Hon. Sec. and Editor,
R.Ae.S. Journal,
7, Albemarle Street, W.1.

16th December, 1925.

Dear Sir,—I thank you for the copy of Mr. W. P. Kemp's letter dated the 10th December and addressed to you. In compliance with your request, I have pleasure in dealing with the points raised in Mr. Kemp's letter. His letter makes it appear as if he has based his criticism on certain statements that I made, without having read the whole of the paper. I will deal with the points raised in the order in which they appear in the letter.

The Aircraft Operating Company had no connection whatever with the Orinoco or Burma surveys. The Company was only formed in January, 1923; the Orinoco work was carried out in 1921. It was the Bermuda and West Atlantic Aviation Co., Ltd., who carried out the Orinoco survey and also the original negotiations for the Burma surveys. The history of these negotiations is given partly in my introduction to the paper, on page 603 of your Journal, and in fuller detail by Major Hemming in his remarks which are reported in the third paragraph on page 629 of the Journal.

As regards the fifth paragraph of Mr. Kemp's letter, I would quote from the beginning of my lecture, as shown in the third paragraph on page 603, as follows:—

> "In the meantime conferences between the Survey of India, the Burma Forest Department and Mr. Ronald Kemp, Inspector of Aircraft in India, acting in an advisory capacity, had ended in the two former departments combining to pay for a survey and Mr. Kemp, whose contract with the Government of India was just terminating, entering into a private contract with the Government of Burma to complete the air work required."

I do not think that anyone who has read this could have received from it the impression that the Burma surveys were carried out by the Aircraft Operating Company.

Regarding the sixth paragraph of Mr. Kemp's letter, I fully agree, as stated in my paper, that Mr. R. C. Kemp most successfully organised the whole of the equipment, with the able assistance of Flying Officer Durward on the photographic side. The actual technical organisation and supervision of the survey itself was done by Flying Officer Durward and myself, and I did the whole of the photographic and survey flying, Mr. R. C. Kemp merely confining his flying activities to testing and inter-communication flying.

As regards the next paragraph, Mr. Kemp will find a full description of the Mergui Archipelago Survey in the latter portion of my lecture (see page 619) under the heading of "Tenasserim Reconnaissances."

With regard to paragraph 8, Mr. Kemp implies that I was merely employed to do piloting. As a matter of fact, after Flying Officer Durward returned to India I was in sole technical charge of all photographic and mosaicing operations, and actually completed the only fully scaled and rectified mosaic which we prepared—that of Rangoon—while Mr. R. C. Kemp was absent in England.

Regarding paragraph 9, I do not understand what Mr. Kemp means. My paper had nothing whatever to do with the Aircraft Operating Company, and the Aircraft Operating Company have not been responsible for the publication of any such letter as that referred to by Mr. Kemp.

Finally, I should like to disabuse Mr. Kemp's mind of the fact that there is any impression in aeronautical circles that the Aircraft Operating Company were responsible for the Burma surveys. This has been made abundantly clear by the correspondence which has appeared in the Press from time to time. In fact, the *Times* published three letters from a director of the Aircraft Operating Company in which attention was called to the valuable work that was being carried out by Mr. Kemp. (See the *Times* of the 10th April, 12th May and 22nd August, 1924.)

In closing, I would refer Mr. Kemp to his brother, with whom I had the pleasure of working, as I feel sure that he will agree with what I say, seeing that he has an intimate knowledge of the whole of the negotiations and subsequent operations.

Yours faithfully,

C. K. COCHRANE-PATRICK.

The Secretary, Royal Aeronautical Society,
7, Albemarle Street, London, W.1.

2, Regent House, Wellington Place,
St. John's Wood, London, N.W.8,
15th December, 1925.

Sir,—I crave your permission to refer to Major Cochrane-Patrick's argument in his reply to the discussion on his paper on "Air Surveys in Burma," printed in the Journal for December. My sole object is to correct certain wrong impressions which may be obtained from the fervour of his advocacy.

Let me say at once that we are both entirely agreed as to the efficacy in general of his method given a suitable type of machine. In fact we have jointly worked out the details of a suitable forward steering and overlap sight.

At this stage in the development of the magnetic compass, in the weather conditions necessary to an air survey, it is not correct to say that the compass is an inaccurate instrument. It is beside the point to suppose a pair of pliers left near it. One does not leave a spanner in the crankcase after an overhaul. True, the compass must be accurately swung, but let it not be supposed that this is a difficult or inaccurate process. In fact with a twin-engined machine it is a very simple matter. The engine, too, requires careful maintenance.

Nor again is it correct to say that only a highly skilled pilot can steer a compass course at all. Every one of the Continental Air Line pilots, with whom I have flown, can steer an accurate compass course, and while I hasten to add what is indisputable, that none are more highly skilled, yet one may be allowed to draw the inference that what a whole body of pilots can do, can be repeated by others. In any case, an air survey pilot is of necessity a highly skilled man.

As to the possibility of steering within half a degree, it is doubtful if any machine can be held on one course within half a degree, whatever the point of reference.

The compass is an instrument of such vital importance in the development of air transport that it would be a thousand pities if it were to lose one iota of the confidence which is justly reposed in it, from a misconception of arguments, which are not really intended to have that effect.

The reference to the air-speed indicator as an inaccurate instrument does not take account of the very simple corrections which may be applied to get a close approximation to the true air speed.

One could quote many cases of remarkable results which have been attained by a careful use of these instruments, but your space is too valuable. Is it necessary to do more than refer to the navigation of Admiral Coutinho combined with the piloting of Captain Cabral on their flight from the Cape Verde Islands to St. Paul Rocks? This, I admit, is not quite relevant to the closer points of the argument, but one must ensure that the arguments against the compass do not secure too literal an interpretation or too wide an application.

As to the comparisons of processes, Nos. 1, 2, 3 and 4 are carried out on the way to the objective, which is in any case "dead flying." The bugbear of changing wind, I am sure from experience and meteorological data, is not so serious everywhere as Major Cochrane-Patrick fears. It should be remembered, too, that these processes give certain additional information of value not given by the other method. The comparison table is made to look a little more formidable, too, by the rolling of several processes into No. 3 of the "contra" table. It is admitted, of course, that the whole process is simpler if a steering sight is used as well as the compass.

The use of the compass and drift sight comes in particularly for the steering of parallel strips when it is not possible to pick out landmarks a long way ahead. If you cannot recognise the points selected by your overlap sight except close to the machine, there is only one instrument which will enable you to fly parallel to the first strip and that instrument is the compass combined with a knowledge of the drift on that particular desired track. It is not my opinion, but the opinion of many operators with wide experience in different countries, that such conditions exist. Also one can point to some extraordinarily successful pieces of work carried out with the compass alone without reference to landmarks. Therefore, while I agree that Major Cochrane-Patrick's system will often be sufficient in itself, I do not think the cumulative experience of so many other operators can be ignored. Personally, I favour a combination of the compass with the steering sight.

Finally, let me add that I would not put a highly paid man on the machine to do the navigating. Whether the photographer is highly paid or not, he is a necessity, and I would make him, as is customary except in Canada, carry out any necessary observations.

I am, Sir, your obedient servant,

F. TYMMS.

The Secretary, Royal Aeronautical Society,
7, Albemarle Street, London, W.1.

REVIEW

By Airplane Towards the North Pole

By Walter Mittelholzer.

This book adds nothing to the Science of Aerial Survey, though it is another instance of the inestimable value of even "interesting views of the local landscape" taken from the air, as one of the writers puts it, in the study of unknown country.

The Expedition, of which this is the story, set out with a Junker seaplane to establish by air a petrol dump on the ice-pack at a point which Amundsen could reach in his first proposed flight across the North Pole in 1923. In the original scheme a miscalculation had been made and it was only at the last moment that it was found that Amundsen's machine could not carry sufficient petrol to reach Spitzbergen without refuelling. As the ice-pack moves at times as much as twenty knots in twenty-four hours it was probably fortunate for those concerned that the special undercarriage built for Amundsen's machine in America proved too weak for the work and collapsed on the first trial landing. In consequence the flight was abandoned.

The auxiliary Expedition decided to continue their journey to Spitzbergen to take aerial photographs there. They had with them the necessary cameras and cinema outfit as it was their original intention to take photographs after their principal work was done in order to assist to defray expenses.

The haste with which the Expedition set out is shown by the fact that they had not even a spare magneto, and it was owing to this that they only made three flights in Spitzbergen. Of these, one was a social visit to a neighbouring coal-mine, one a preliminary reconnaissance and trial flight, and only one a complete exploratory flight. Even this last would not have been completed had it not been for the extreme keenness and daring of the pilot and photographer, as from an early stage in the flight their engine would not run on full throttle without misfiring. Nevertheless they continued and completed a flight from their base on the west coast across the centre of Spitzbergen and back round the northern coast of the island. On landing they found one magneto to be useless and the seaplane would not rise off the water with the other magneto alone.

That the photographs taken on this one flight were of considerable geographical and geological value, in spite of the fact that no special system was adopted in the taking of them, proves again how invaluable a properly-organised aerial survey can be.

The book opens with a short and simple but most interesting description of Spitzbergen and the local conditions by Professor Wegener, who accompanied the Expedition in an advisory capacity, as he had spent some time in the island before the war. It ends with a general story of the Expedition chiefly in diary form by Lieutenant Mittelholzer, of the Swiss Air Force, who acted as observer and took all the photographs. Between these two portions we have a chapter on photography from the air which deals with the general points to be considered in aerial photography in Arctic regions in order to obtain the necessary sharpness of detail, and a chapter on the geographical value of the photographs.

These two chapters are by writers who were not members of the Expedition, and it is probably owing to this that their remarks are more of a general nature than dealing with the work actually done. It would be most interesting to know if the methods recommended in the former chapter were actually used, and further details would have been welcome as to the data from which the grids, applied to some of the obliques, were prepared.

Nevertheless, the quality of the numerous photographs reproduced is excellent, considering the extremely difficult light conditions, and the combined book makes interesting reading.